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UNITED STATES NAVY

REPORT ON PHASE II
of the
PRESSURE-HEIGHT PREDICTION PROJECT

VOLUME I

PROJECT AROWA

Bureau of Aeronautics Project Arowa (TED-UNL-MA-501)
"Applied Research; Operational Weather Analysis"
(AROWA)

U. S. Naval Air Station
Building R-48
Norfolk, Virginia

CONFIDENTIAL AFSWP Report # 717

BUREAU OF AERONAUTICS PROJECT AROWA (TED-UNL-MA-501)
"Applied Research; Operational Weather Analyses"

Report on Phase II

of the

Pressure-Height Prediction Project

Volume I

BUREAU OF AERONAUTICS PROJECT AROWA
BUILDING R-48
U.S. NAVAL AIR STATION
NORFOLK 11, VIRGINIA

April 1954

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INTRODUCTION

This is a report on Phase II of the Pressure-Height Prediction Project. It describes the research conducted at Bureau of Aeronautics Project AROWA under the sponsorship of the Armed Forces Special Weapons Project on Phase II of this project.

The report is divided into three volumes. Volume I contains a brief summary of the problem and research accomplished to date, a discussion of some immediately operational procedures, an outline of the meteorological topics in Volume II, and of future planned research.

Volume II is designed primarily for meteorologists. It contains a more complete and technical discussion of prediction parameters and techniques. An attempt is made to objectively describe the flow patterns at 500 mb using both historical and newly devised models. The synoptic significance of long waves, blocking, geostrophic wind profiles and their relation to the proposed operational procedures are outlined.

Volume III is operational in nature and includes examples of the application of the meteorological parameters to the forecast problem.

I. SUMMARY

Phase II of the Pressure-Height Prediction Project is aimed at providing techniques for fulfilling the meteorological requirements of baro-fusing systems, including the prediction of typical atmospheric structures prevailing at designated areas, the production of a graph of predicted pressure altitude versus actual altitude above mean sea level for designated areas, an estimate of the accuracy of meteorological predictions with regard to the estimated standard deviation of pressure-altitude prediction as a function of geographical location and time of year, and the magnitude of errors involved in the selection of pressure altitudes directly from graphs representative of numbered atmospheres.

Techniques for predicting pressure altitude at given geometric heights have been developed for various conditions of meteorological data availability and operational procedures. The three basic conditions of meteorological data availability considered include:

(a) Complete data availability. (This condition is considered present in peace, and under wartime conditions if free international exchange of meteorological observations were maintained).

(b) No data availability. (This condition would be encountered by a forecast group having no analyzed meteorological data).

(c) Partial data availability. (This condition assumes data coverage over a portion of the hemisphere and absence of data over the

remainder. It will be encountered primarily when a prediction is required for an area from which no meteorological data is received).

Under data condition (a) above, the meteorologist will prepare his prognostic charts for various pressure levels by standardized techniques in daily use. Pressure-height computations are then made to predict the pressure altitude at the appropriate geometric height. The technique which was particularly designed to facilitate this type of computation is fully described in Appendix A to the First Progress Report on Phase II of this project, entitled "Use of the PASTAGRAM in Pressure-Height Computations". This has been further distributed as NAVAER 50-1P-501 with the same title. It provides a means for obtaining accurate values of pressure altitude under this condition of data availability.

Under data condition (b) above, a prediction must be based upon climatologically probable values. To provide climatological values for all points in the northern hemisphere, a complete set of normal pressure-altitude charts for the hemisphere for each month at thousand-foot levels from the surface to 10,000 feet was constructed. These charts are contained and their use fully explained in Enclosure 1 to the Second Progress Report on Phase II of this task. They have been further distributed as NAVAER 50-1C-502 entitled "Normal Pressure-Altitude Charts for the

Northern Hemisphere". These provide a means for obtaining the most probable values of pressure altitude under conditions when meteorological data is completely lacking. They also provide a consistency check on forecasts prepared with complete or partial data availability.

Under data condition (c) above, the complete range from normal availability to total absence of meteorological data is experienced. It is on this condition that the greatest research effort has been applied.

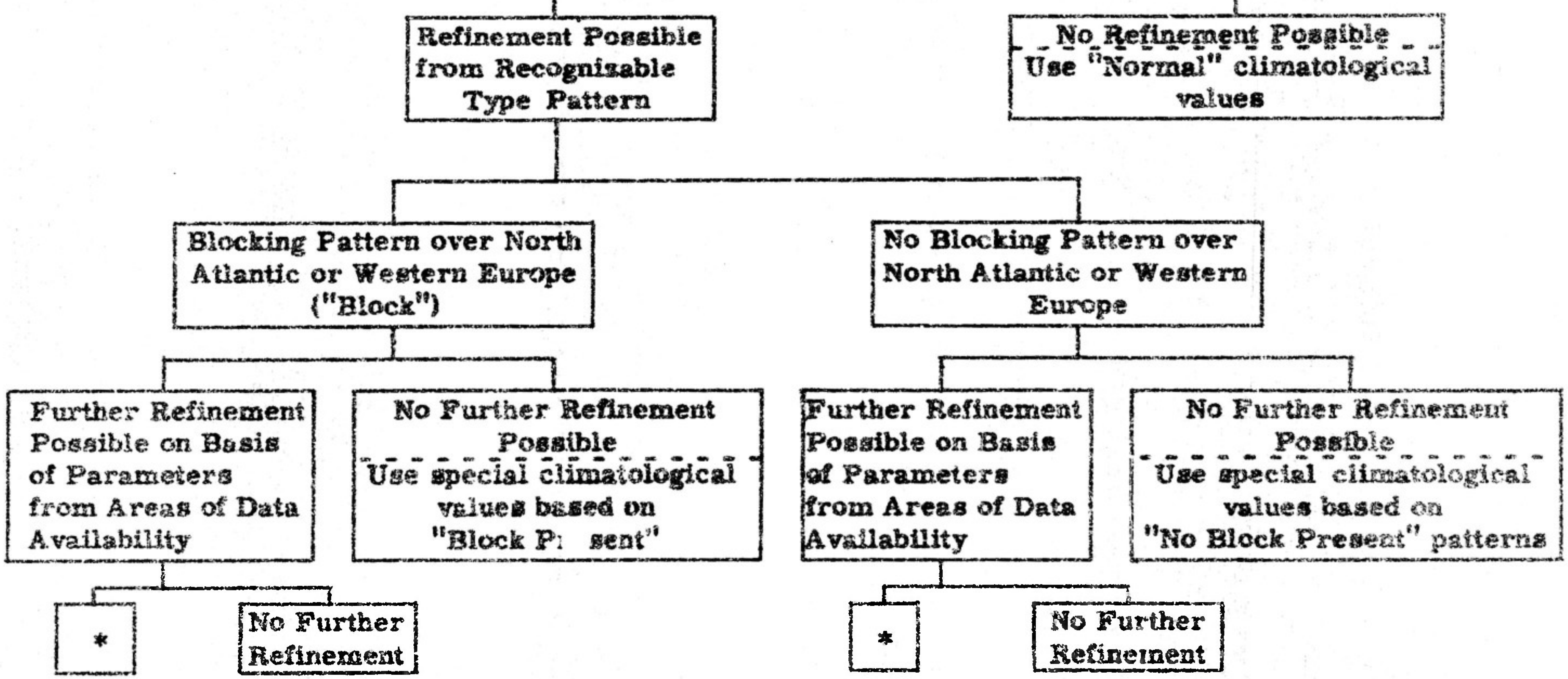
For targets less than 300 miles within a "blind area" (devoid of meteorological data), extension of procedures employed under condition (a) (complete meteorological data available) are utilized. For targets more than 300 miles within a blind area, special techniques are required. These techniques provide a series of refinements to the climatological prediction of pressure altitude. They are based on prediction of atmospheric circulation features involving larger areas and longer time intervals than employed in conventional forecasts. When the area without data is large, the forecast must depend upon large scale, slowly moving features of the circulation. These are the features which produce large and persistent anomalies in pressure-altitude values. Hence the prediction schemes based on them are most successful when the departures from climatological values are large.

Figure 1 shows the general prediction scheme under data condition (c) where the forecast is to be made for a blind area. Details of this procedure are contained in the main body of this report.

In addition to the prediction techniques which may be applied at a meteorological forecasting center, methods for obtaining pressure-altitude values at flight levels from navigational parameters, or simple meteorological observations, available in the delivery aircraft under differing operational procedures are discussed. In particular, methods are described whereby pressure-altitude values may be obtained by personnel in delivery aircraft which, (a), approach at low level and then climb to a high level from over a surface of known height, and, (b), which approach at high level and can determine both their true and pressure altitudes at flight level at some point during the flight, even though far removed from the target. The details of these procedures and results of operational tests are contained in Volume I - Chapter III of this report.

The prediction of appropriate numbered atmospheres, extrapolative procedures involved in prediction techniques developed in the main body of the report, and the errors in terms of the estimated standard deviation of pressure-altitude prediction as a function of geographic location and time of year are discussed.

Figure 1
Schematic Representation of Forecast Procedure



* Separations continue, and choices between refinement and no refinement are made based on parameters from areas of data availability, i luding:

1. Position of long waves
2. Zonal profile values
3. Height changes, and height-change tracks
4. Regime changes

All available historical data at 500 millibars (pressure altitude of 18,280 feet) were processed with the aid of punched card machines. A climatology of heights at 500 millibars was obtained. Tabulations of the frequency distributions of heights and 24-hour height changes were prepared The seasonal and geographic variation in the height of this surface is shown in Figure 2. Figure 3 illustrates the range of actual heights at this pressure level in April. Samples of the frequency distributions of the heights, illustrating the geographic variation in the shapes of the distributions, for January are shown in Figure 4.

Figure 5 illustrates the values of forecast error at 5,000 feet over a portion of the hemisphere during April. The isopleths of forecast error represent the values which will not be exceeded 68% of the time. These values shown for April are intermediate between the larger January values and the smaller errors in July. They approximate an annual average.

The major portion of the research effort applied to Phase II of the Pressure-Height Prediction Project was directed at providing an objective system for forecasting pressure height at the 500-millibar level (18,280 feet), and extrapolating downward, or upward, through the atmosphere to any desired level.

In effect, the procedures developed yield a prediction at the 500-millibar level and require an extrapolation based upon the slope

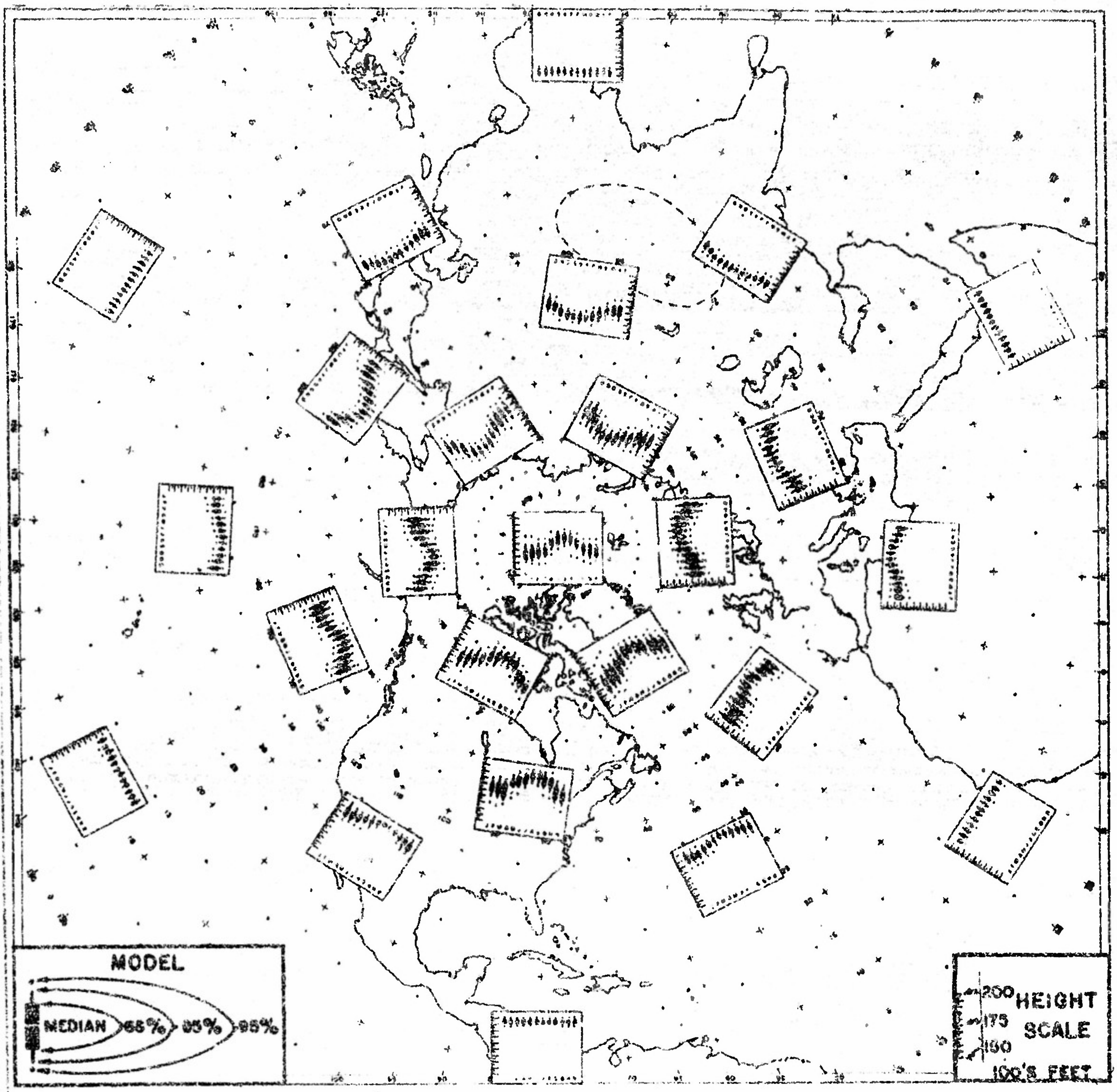


Figure (2). Seasonal and Geographic Variation of 500-mb Heights

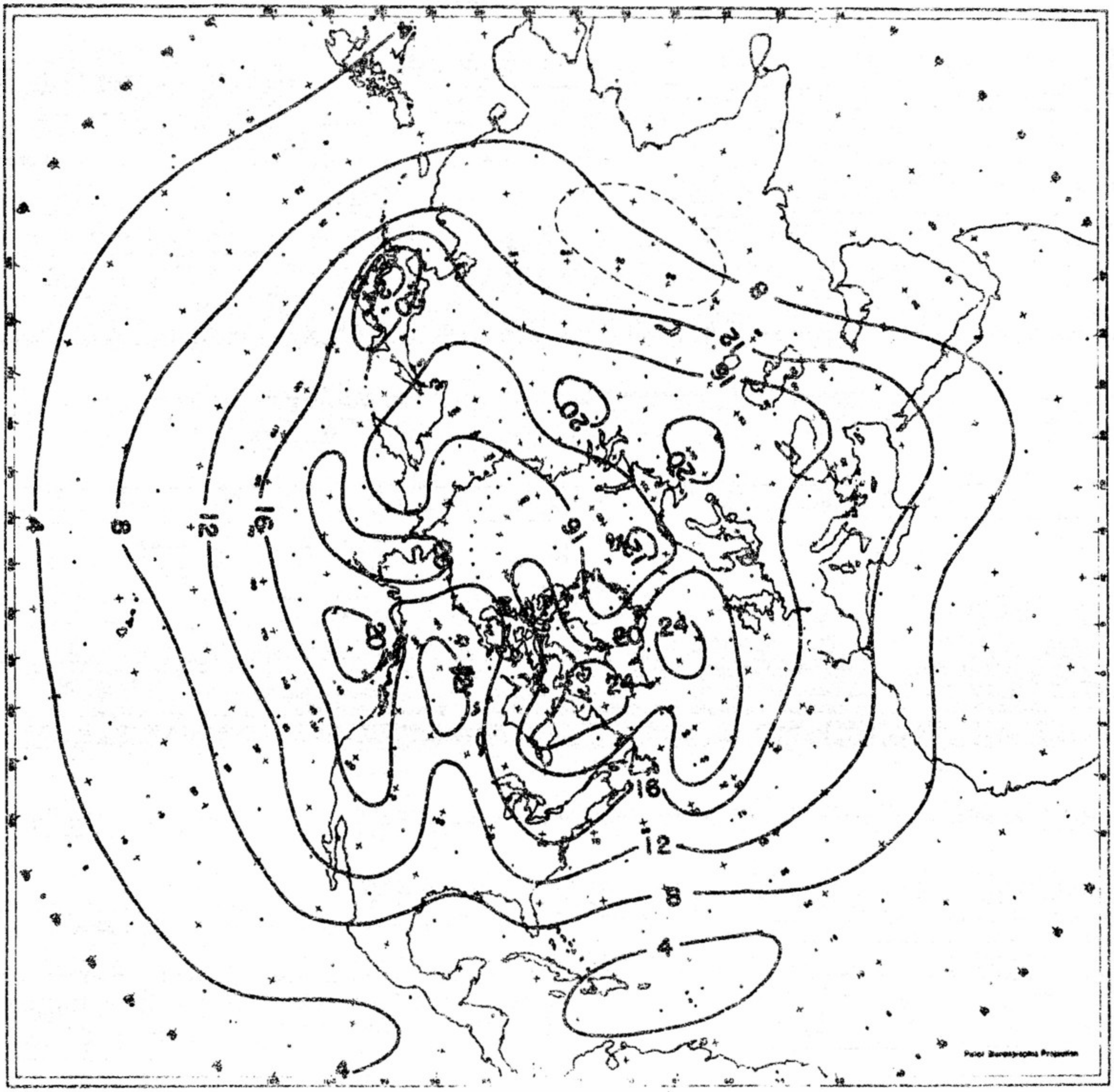


Figure (3). Range of Actual Heights at 500 mb (Z_p = 18,280 feet) in April
(hundreds of feet)

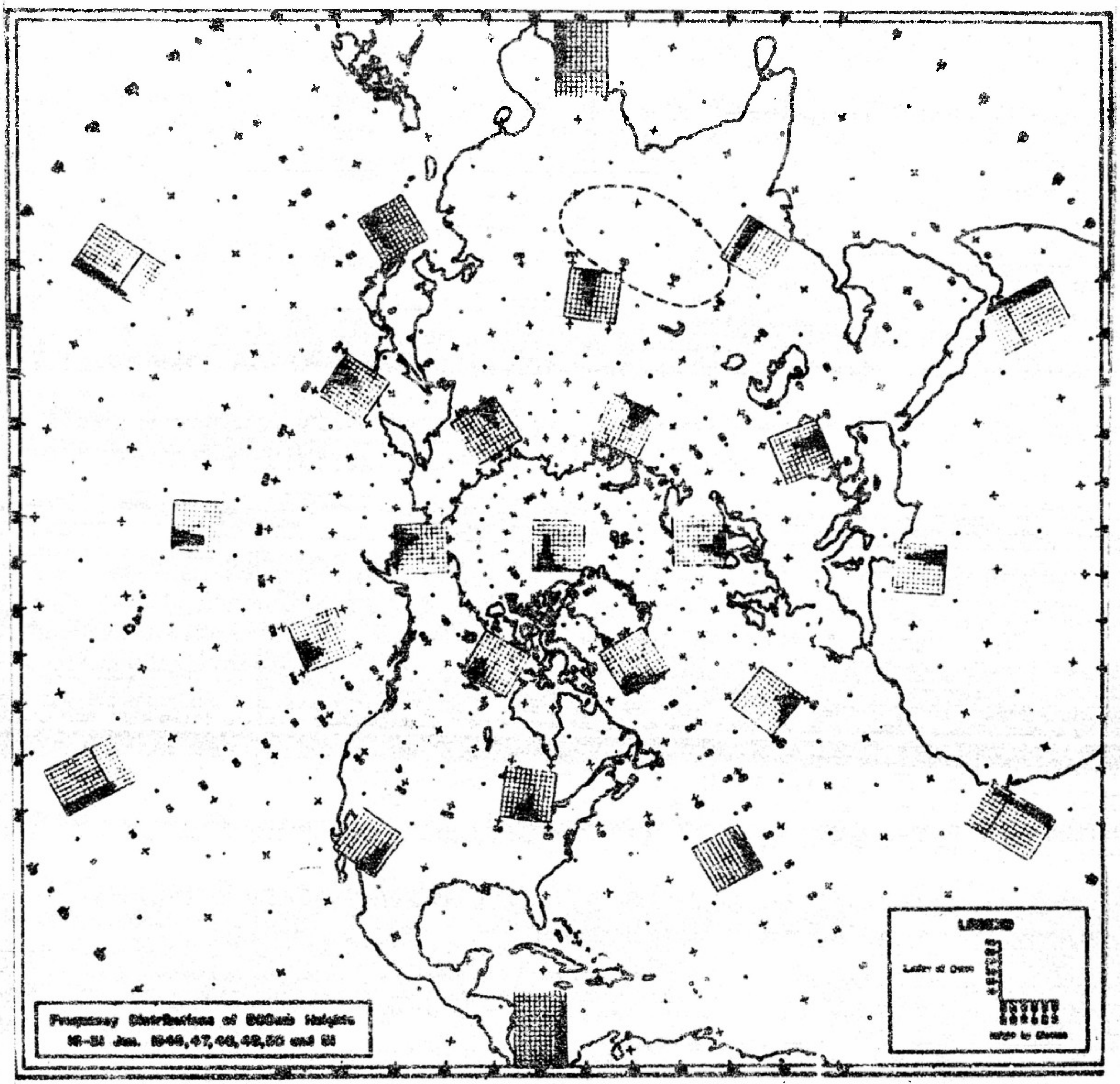
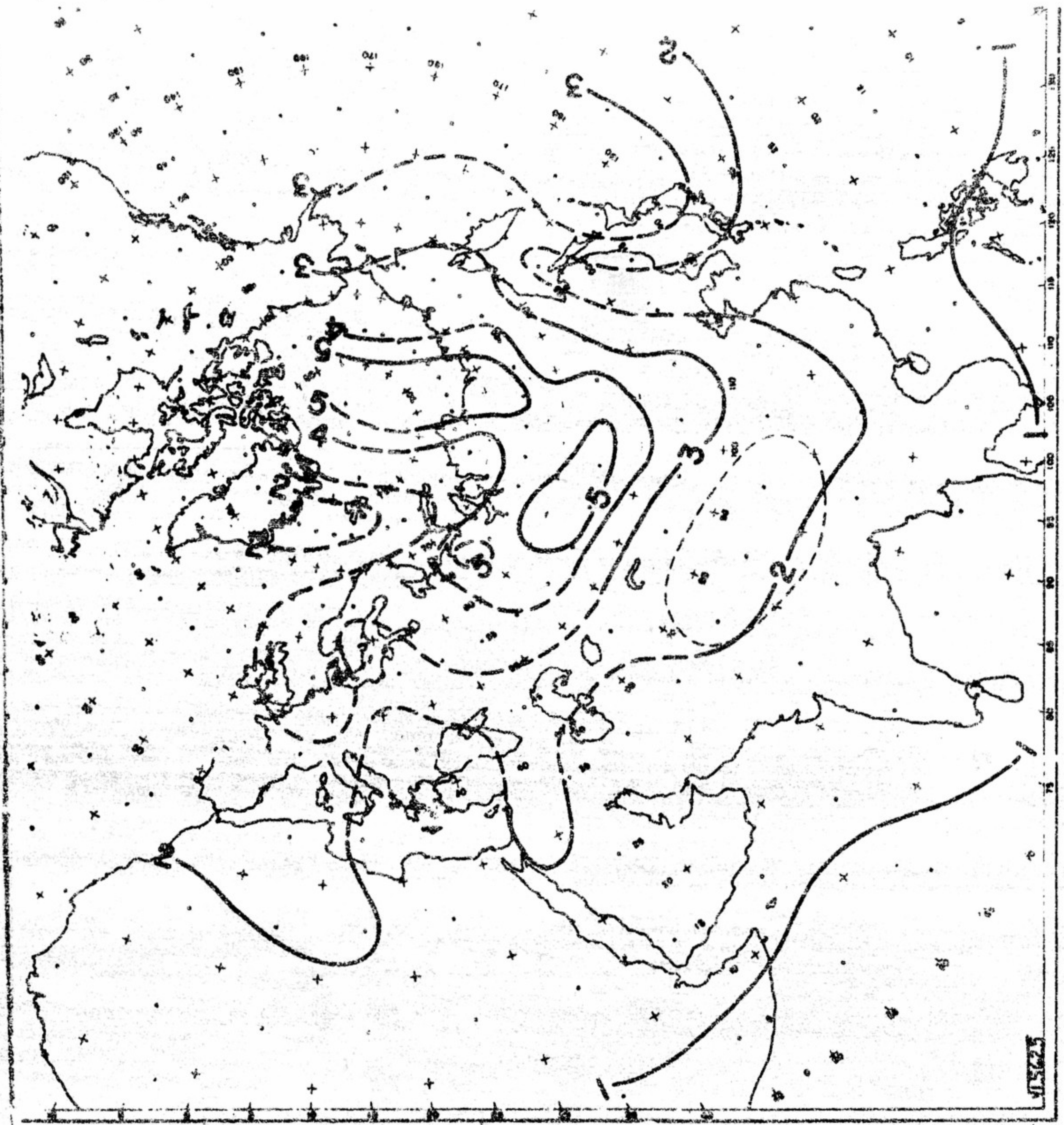


Figure (4). Frequency Distributions of 500-mb Heights 16-31 January 1946-1951



Isopleths of forecast error ~~is~~ in hundreds of feet 68% of errors are smaller than values shown ________ Actual — — — — Estimated

Figure (5). Forecast Error at 5,000 Feet in April of a line through that level on a thermodynamic diagram. A set of charts for this extrapolation under normal conditions is contained in Volume I - Chapter IV.

A simultaneous prediction of the pressure height of the 500-millibar surface and at sea level with intermediate values obtained through interpolation will provide considerably more accurate values of pressure height for the lower levels of the atmosphere. Work was initiated to develop a procedure for accomplishing this. At the same time additional research was undertaken to increase the accuracy of 500-millibar prediction, and to investigate the role of vorticity in the development of circulation features at this level.

The Armed Forces Special Weapons Project is supporting this continued research at Project AROWA, and under contract through AROWA at the Aerophysics Research Foundation.

II. DISCUSSION

Because of the apparent increase in height of the level for which forecasts may be desired, and the availability of reliable data on which to base the development of an effective prediction technique, the 500-mb pressure envelope was selected as the level at which techniques for a basic prediction would be made. Further techniques would then be applied to compute the pressure height at any prescribed altitude.

The basic data utilized in this development has been provided by the analyzed series of 500-mb charts contained in the Northern Hemisphere Historical Weather Maps, and the Daily Series, Synoptic Weather Maps, published by the U. S. Air Force and the U. S. Weather Bureau, respectively.

Attention has been concentrated on those patterns which are either readily recognizable, or represent extreme values of height or 24-hour height change in the areas of interest. Forecasts for the remainder of cases not included in the system must then be based on the best available climatological figures.

The variability of pressure, or pressure altitude, is a function of season, latitude, and synoptic situation. The relative importance of different levels in producing pressure changes varies geographically.

If a knowledge of the permissible error were available, it would be possible to outline the geographic limits where pure climatology would provide ~~acceptible~~ acceptable answers. In the absence of such knowledge it has been feasible only to present charts delineating the error, or variability for arbitrarily selected ranges of pressure altitude.

The accuracy of any prediction scheme is a function of the difficulty of the prediction. This, in turn, is a function of both the pressure variability and the quantity of data available.

Early in the study, attempts were made to develop an empirical objective scheme for relating pressure altitudes at fixed geographic points with synoptic patterns. These showed the need for a sound physical synoptic approach and the application of synoptic models rather than straight empiricism.

The forecast procedures are functions of the season, the pressure altitude required, geographic location, the availability of data, and synoptic conditions. With the development of an adequate climatological system to provide answers for the central range of values, the importance of recognizing situations resulting in large anomalous values becomes paramount. In the absence, or partial absence of data, the extension of patterns in space or time is required. Fortunately the large scale features of the atmospheric circulation, which produce the major anomalies, are seen most clearly when a smoothing technique in space or time is employed. Thus the techniques which have already been extensively investigated by research and operational groups involved in long-range forecasting are the ones most applicable to this problem.

Earlier progress reports on this task stressed the importance of blocking patterns in the 500-mb circulation, as have most studies of long-range forecasting. Theoretical models of the atmospheric circulation contain a belt of westerly winds in middle latitudes undergoing a wave motion. The characteristics and motions of these waves in the westerlies have been intensively studied in recent meteorological history. During relatively long periods of time the progression of the wave pattern is blocked by persistent high pressure areas in the upper atmosphere. These blocking patterns are responsible for large anomalies in pressure-height over specific geographic areas. Recognition of a blocking pattern is essential to the success of any pressure-height prediction scheme.

Though long waves and blocking are treated separately in Volume II, their studies are intimately related. A portion of the research on this task has been devoted to investigations of procedures for objectively locating and describing the long waves. A review of long wave analysis, a description of time averaged charts, the results of research utilizing space averaged charts, an analysis of blocking and zonal wind studies are fully discussed in Volume II.

III. IN FLIGHT COMPUTATIONS

A. Vertical Ascent

The value of the pressure altitude or true altitude at desired levels in the atmosphere may be computed by personnel within an aircraft if the values of both actual and pressure altitudes at any level are measured and knowledge of the vertical atmospheric temperature distribution is available. The procedure employed is illustrated by Examples 1 and 3 of NAVAER 50-1CP-501, "Use of the Pastagram in Pressure-height Computations". The special case wherein the temperature distribution is obtained by direct measurement from the aircraft is demonstrated below.

(1) Obtain a value for the geometric height at the base of the ascent.

This may be accomplished by a radio altimeter if over a location whose height is known, such as open sea, inland lake, plateau or other flat terrain of known height.

(2) Obtain a simultaneous value for the pressure altitude at this point from the pressure altimeter.

The altimeter setting should be adjusted to 29.92 and the pressure altitude read directly.

(3) Subtract the value of the pressure altitude (Zp) from the geometric height (Z) to obtain a value of the "altimeter correction" (D) by the equation:

$$D = Z - Zp$$

(4) At frequent intervals during ascent (every one thousand feet of pressure altitude) record values of pressure altitude and of free air temperature (thermometer reading corrected for true air speed).

(5) Plot these values on a Pastagram for each level from the base to the top of the ascent.

(6) Count the number of 10-foot areas contained on the Pastagram between the plotted sounding and the standard atmosphere line from the base of the ascent to the desired level. Areas to the right of the standard atmosphere line are counted as positive. Those to the left are negative.

(7) Add algebraically the number of 10-foot areas obtained in Step 6 to the value of the altimeter correction at the base of the ascent obtained in Step 3. This will yield the value of the altimeter correction (D) as the desired level.

(8) Apply the equation:

$$Z = Z_p + D$$

to obtain the geometric height at the pressure height nearest the desired level.

(9) Apply the same equation to obtain the geometric height at the next higher, or lower, measured pressure altitude to bracket the desired geometric height. (Remember to add or subtract as appropriate to the value of D the number of 10-foot areas included in this thickness of the atmosphere between the level of Step 8 and this new level.

(10) Find by interpolation the pressure altitude at the desired geometric height from the values of geometric height (Z) and pressure altitude (Z_p) obtained in Steps 8 and 9.

When the geometric height can be measured directly with a radar altimeter over a water or other flat surface, the pressure altitude may be obtained directly from a pressure altimeter set of 29.92. To obtain a graph of true altitude vs. pressure altitude under these conditions it is necessary only to record the readings of radar and pressure altimeters respectively during the ascent.

Through the cooperation of a Heavy Attack Training Unit, operational tests of the procedure were conducted. It was found that the pressure altimeters and thermometers in all aircraft involved had to be calibrated. Once this was accomplished the results attained indicated the feasibility of utilizing this technique in operational type aircraft on a routine basis. Figure (6) illustrates an example of the form of Pastagram used for these tests with a plotted soundings. The data on this flight were obtained on 16 October 1953 at 0840 in the vicinity of Cape Hatteras N. C. At the 9,000 foot level, the height was computed and compared with the two radar altimeters installed in the aircraft. The results were:

Indicated pressure altitude	9,000 feet
Pastagram correction ~~connection~~	+ 330 feet
(33 squares, each worth +10 feet)	———
corrected ~~Connected~~ altitude	9,330 feet
Radar altimeter #1	9,320 feet
Radar altimeter #2	9,330 feet

Comparison ~~Compairson~~ of 23 soundings obtained from these aircraft with radiosonde observations showed that differences at the 10,000 foot level ranged from -120 to +90 feet while the absolute value of the average difference at this level was 32 feet.

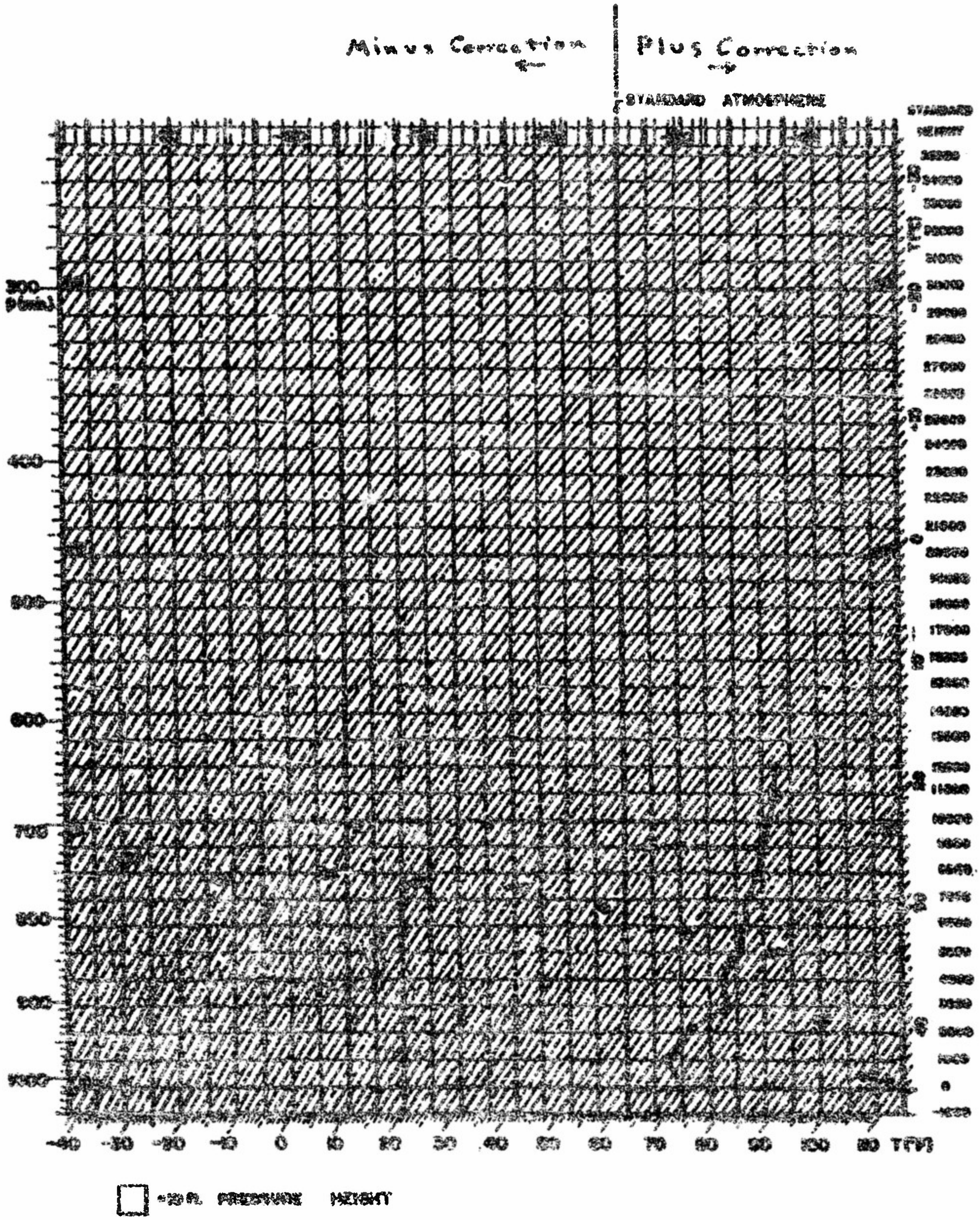


Figure 6. Pastagram With Plotted Sounding Used for In-Flight Computation.

B. Horizontal Flight

The geometric height of an aircraft which has flown across a coast line or over land of known height may be computed from navigational wind data. Since it is often quite difficult to determine accurately the height of a particular land surface beneath an aircraft, a computation of the aircraft height from navigational parameters will often be required. The successful computation requires a knowledge of the geometric and pressure altitudes of the aircraft at some previous time, the net wind drift since that time and the pressure altitude of the plane at the desired point.

Utilizing both pressure and radar altimeters while over water, or terrain of known height, a computation of the difference (D) between these is made, by the equation $D = Z - Z_p$, where Z = true altitude and Z_p = pressure altitude. Direct wind observations at the flight level of the aircraft are made, usually by checking the navigation. The change in the value of D at the flight level, which is at a constant pressure surface if flight is maintained at a constant reading of the pressure altimeter, between the observation point and any desired point to which the plane travels is computed from the equation for the geostrophic wind.

$$V_n = \frac{21.4}{\sin \phi} \left(\frac{\partial D}{\partial n}\right)_p$$

Here, V_n is the component of the wind in knots normal to the line joining the two points

ϕ is the latitude of the mid point of this line

δD is the value of the change in D in feet at flight level

δn is the distance in nautical miles between the two points.

Since the value of the change of D is required, the equation is rearranged and written in terms of finite differences. It then has the form

$$\Delta D = \frac{V_n \sin\phi \, \Delta n}{21.4}$$

Here the meanings and units are the same as above, except that the symbol δ has been replaced by Δ. The latter equation is solved for ΔD. This change in D is added algebraically to the earlier observed value of D to obtain the value of D at the desired point. This value is independent of forecast errors and of any constant instrumental errors of the pressure altimeter.

The geometric height (Z) of the aircraft is then obtained by adding the value of D to the pressure altitude (Zp) given by the altimeter.

$$Z = Z_p + D$$

A calculation of the pressure height or true height at any point below the aircraft may then be made by use of the Pastagram, if a prediction or measurement of the atmospheric structure is available.

In the absence of an observation, either the prediction of the atmospheric structure (expressed as a sounding or the atmospheric number provided by the forecaster) or downward extrapolation by the coefficients of Figures (7) through (30) of Chapter IV may be utilized to obtain the pressure altitude at a lower geometric height.

The example below illustrates the computation at flight level:

A plane flying at 4,000 feet by the pressure altimeter crosses a coast line toward land. The radar altimeter indicates the true height of the aircraft to be 4,490 feet. The flight path carries the plane 1,200 miles inland. Wind drift checks reveal the average cross wind along the flight line to be 40 knots from left to right. The latitude of the mid point of the flight path is 48° N. The geometric height above sea level is computed as follows:

(1) D at coast is 4,490 feet -4,000 feet = +490 feet

(2) $\Delta D = \dfrac{V_n \sin \phi \, \Delta n}{21.4}$

$$\Delta D = \frac{-40 \times .743 \times 1200}{21.4} = -1{,}667 \text{ feet}$$

(Since the wind was from the left, he is flying toward lower heights. Hence the ΔD is negative)

The D at terminal point is +490 - 1,667 = -1,177 feet, and the geometric height above sea level is found by:

$Z = Z_p + D \qquad Z = 4{,}000 - 1{,}177 = 2{,}823$ feet

IV. VERTICAL EXTRAPOLATION

The end product of a complete pressure-height prediction is a graph of pressure altitude versus true height through the range of heights desired. To attain this result a complete prediction of the atmospheric structure is required. Under many of the operational conditions visualized, such a complete prediction is highly improbable. Reasonable approximations, however, may be made by several alternative methods. A few which are immediately applicable are outlined below.

If a prediction of the height of a constant pressure surface is made and a knowledge of the temperature distribution is available, appropriate tables or the Pastagram may be used to compute pressure altitudes at all desired heights. Under anticipated operational routine, a forecast of the height of the 500-mb surface will be made, as well as a prediction of an atmospheric number corresponding to the appropriate lapse condition. This provides an approximation of the needed parameters for construction of the desired graph of pressure altitude against true altitude.

Sets of tables were constructed for each of the numbered atmospheres in use. With these tables and a prediction of the 500-mb height, the meteorologist could compute pressure at any desired height. Unfortunately the numbered atmospheres were replaced with a new set, thereby making the tables obsolete. The new numbered atmospheres have been requested, but have not been received at Project AROWA. New tables will be computed for these atmospheric structures for inclusion in a future report.

In the absence of a knowledge of the atmospheric structure, a reasonable approximation of the pressure altitude at any height may be obtained by vertical extrapolation, either up or down, from any pressure envelope whose height is known or predicted.

The twenty-four charts on the following pages provide the coefficients for this extrapolation. They represent the normal rate of change of "D" for each thousand feet within each of two layers of the atmosphere. There are two charts for each calendar month. The first provides the normal rate of change of "D" between 700 mb and 500 mb, while the second shows the normal rate of change of "D" between the surface and 700 mb.

To use these charts, a forecast of the 500-mb height is obtained. This is then expressed in terms of D at 500 mb. The first chart for the appropriate month is entered at the proper location and the coefficient for vertical extrapolation to 700 mb obtained. If the desired prediction level is between 700 and 500 mb, the "D" at the appropriate height ~~is~~ computed directly. If the desired level is below 700 mb, the "D" at 700 mb is computed from the first chart and the 500 mb prediction. Then the second chart is entered to obtain the coefficient for extrapolation to the desired level. This is illustrated by the example at the end of this chapter.

The procedure outlined here is in effect a "slope-intercept" solution to a graphical problem. The intercept of the height at the 500-mb level is given by the forecast utilizing the parameters discussed in volumes 2 and 3; the slopes for extrapolation are given in the 24-charts included in this chapter.

It is evident that a closer approximation may be obtained by using direct interpolation between two points fixed on a line than by this slope-intercept solution. For this reason, the future work, described in Volume 3 is aimed at providing procedures for obtaining simultaneous prediction of height, and thus "D" at both the 5 00 mb and surface levels.

Example of Vertical Extrapolation

Problem: Predict the pressure altitude at 8,000 feet over Gibraltar on July 15. Assume the 500-mb height is predicted to be 19,500 feet.

(1) Convert this to "D":

$$D = Z - Z_p$$

$$D = 19,500 - 18,280 = 1,220 \text{ feet}$$

(2) Obtain the normal rate of change of D between 500 mb and 700 mb:

This is the inverse of the ~~upper~~ upward extrapolation figure given for 700 mb to 500 mb on the chart. Thus it is read as -65 feet per thousand.

(3) Multiply this coefficient by the number of thousand feet (pressure altitude) of downward extrapolation to 700 mb:

18,280 feet - 9,880 feet = 8.4 thousands of feet

8.4 x (-65) = -546

(4) Add this algebraically to the "D" at 500 mb obtained in Step 3.

1,220 - 546 = 674 feet

Thus the "D" at 700 mb is +674 feet, and the 700 mb surface is at 10,554 feet.

(5) Find the distance required for extrapolating from this level to the desired level (6,000 feet)

10,554 - 6,000 = 4,554 feet

(6) From the second July chart obtain the coefficient for extrapolating from 700 mb downward:

This will be the inverse of upward extrapolation figure given on the chart, and is seen to be -41 feet per thousand.

(7) Multiply the coefficient by the distance in thousands of feet.

-41 x 4.5 = -184.5 feet

(8) Add this algebraically to the "D" at 700 mb to obtain the "D" at 6,000 feet.

674 - 184 = 490 feet

(6) From the equation $Zp = Z - D$ find the pressure altitude at 6,000 feet:

$$Zp = 6,000 - 490$$

$$Zp = 5,510 \text{ feet}$$

Answer: The pressure altitude at 6,000 feet over Gibraltar on July 15th when the 500-mb height is predicted to be 19,500 feet is computed to be 5,510 feet.

This problem was worked on the 15th of a month, since the charts are directly applicable on that date. For all other dates, linear interpolation of the coefficients for the desired points between the 15th of the nearest preceding and following chart may be made.

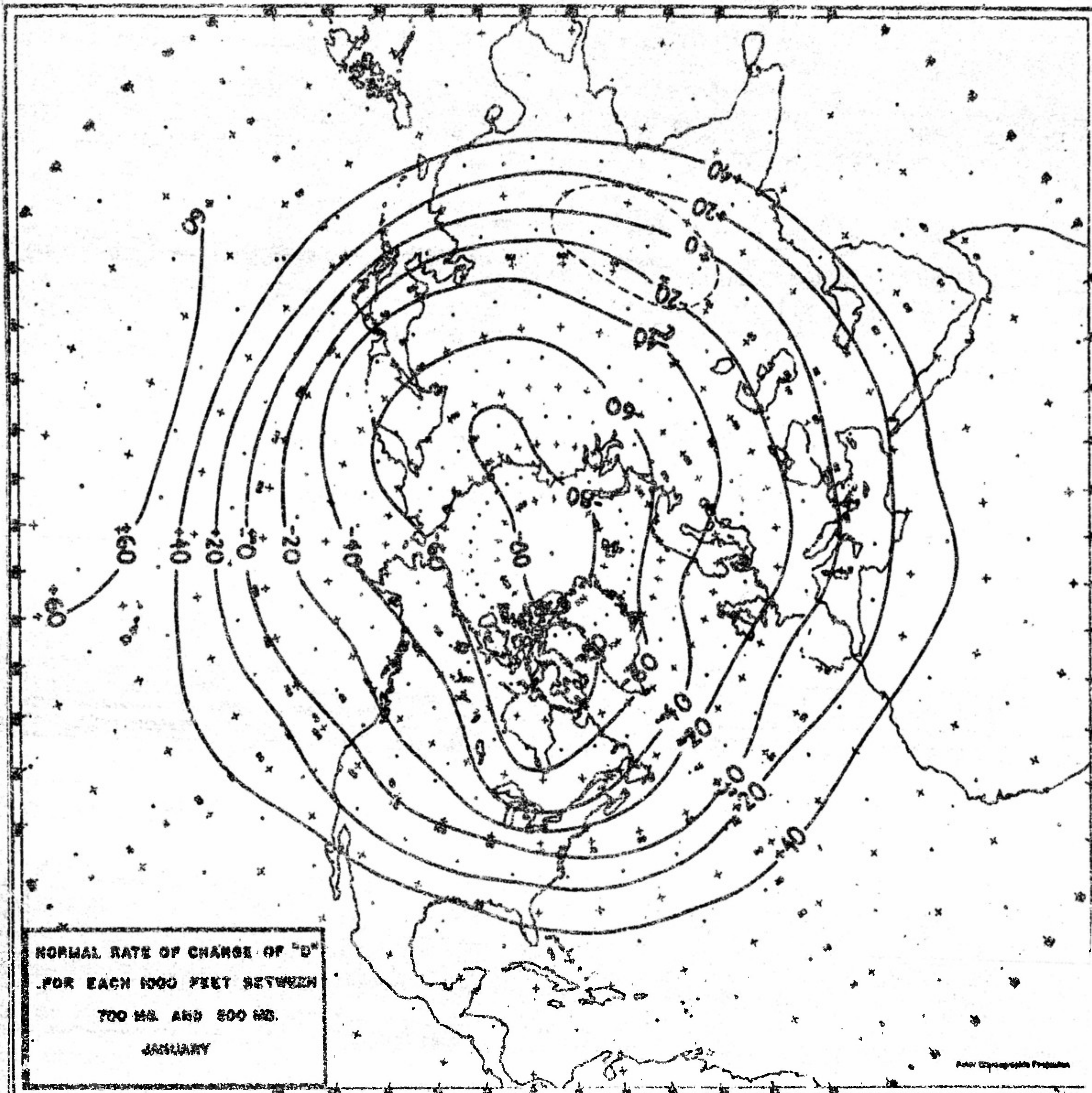


Figure (7). Upward Extrapolation Coefficient 700 mb to 500 mb, January

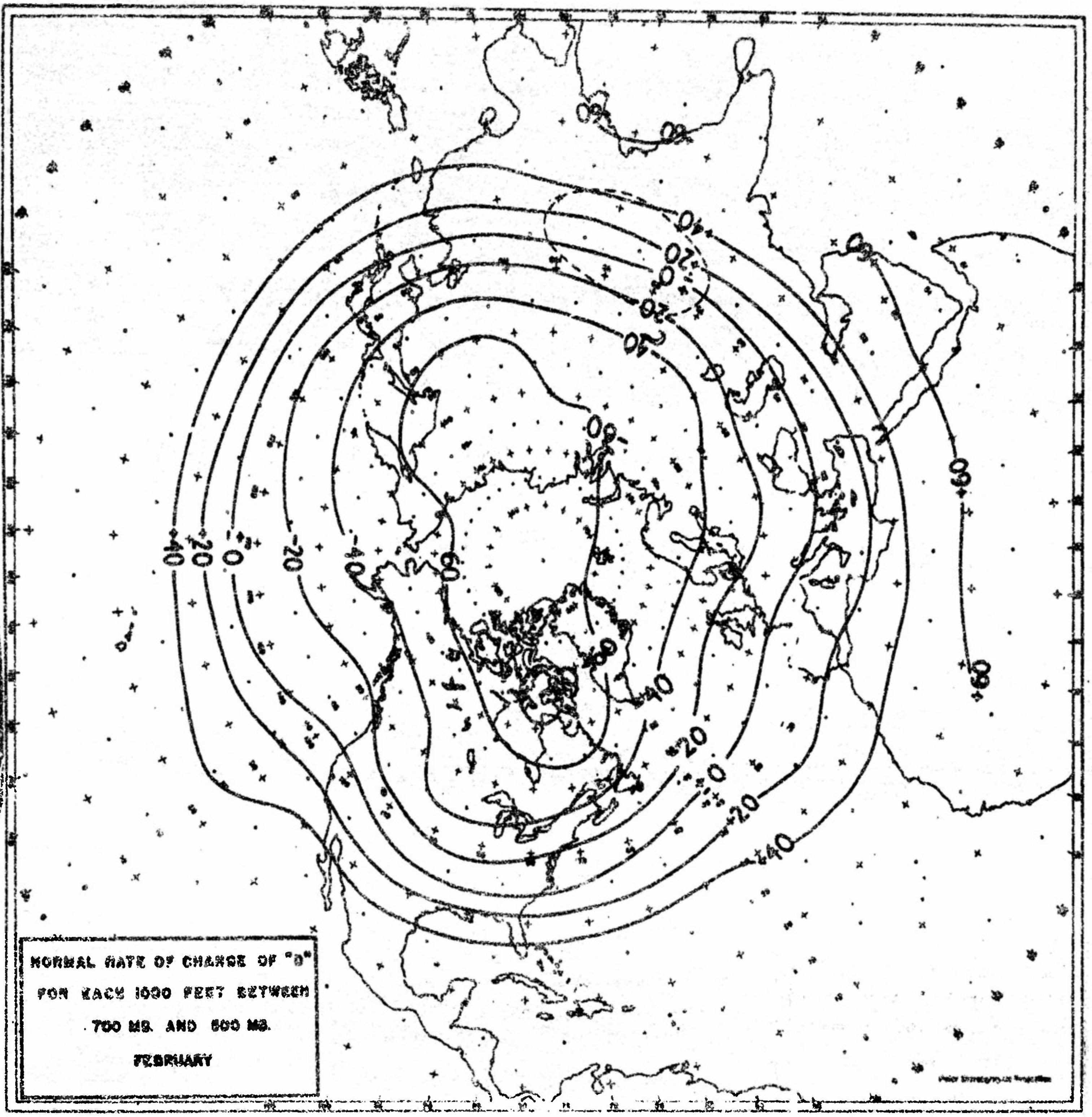


Figure (8). Upward Extrapolation Coefficient 700 mb to 500 mb, February

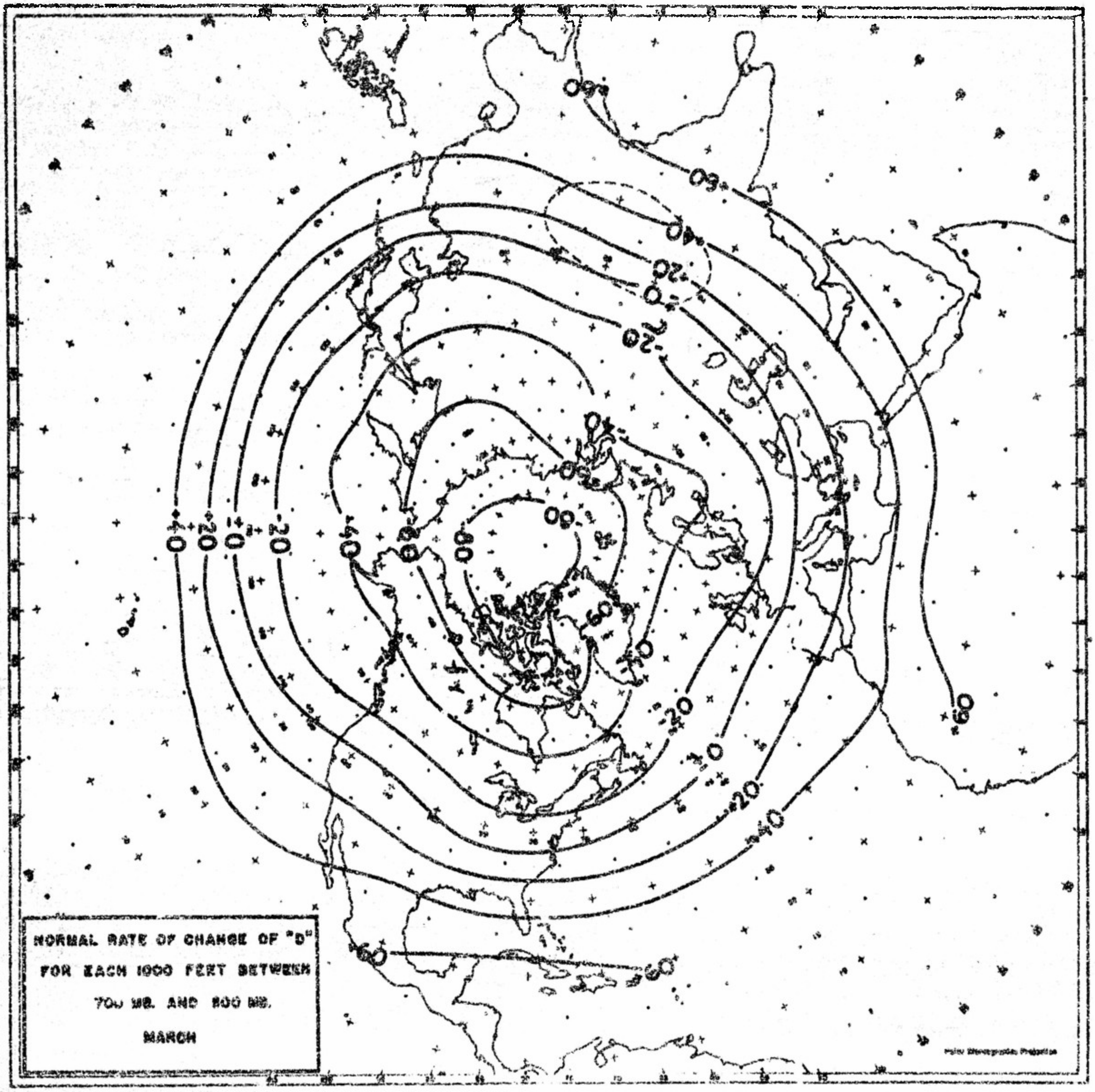


Figure (8). Upward Extrapolation Coefficient 700 mb to 500 mb, March

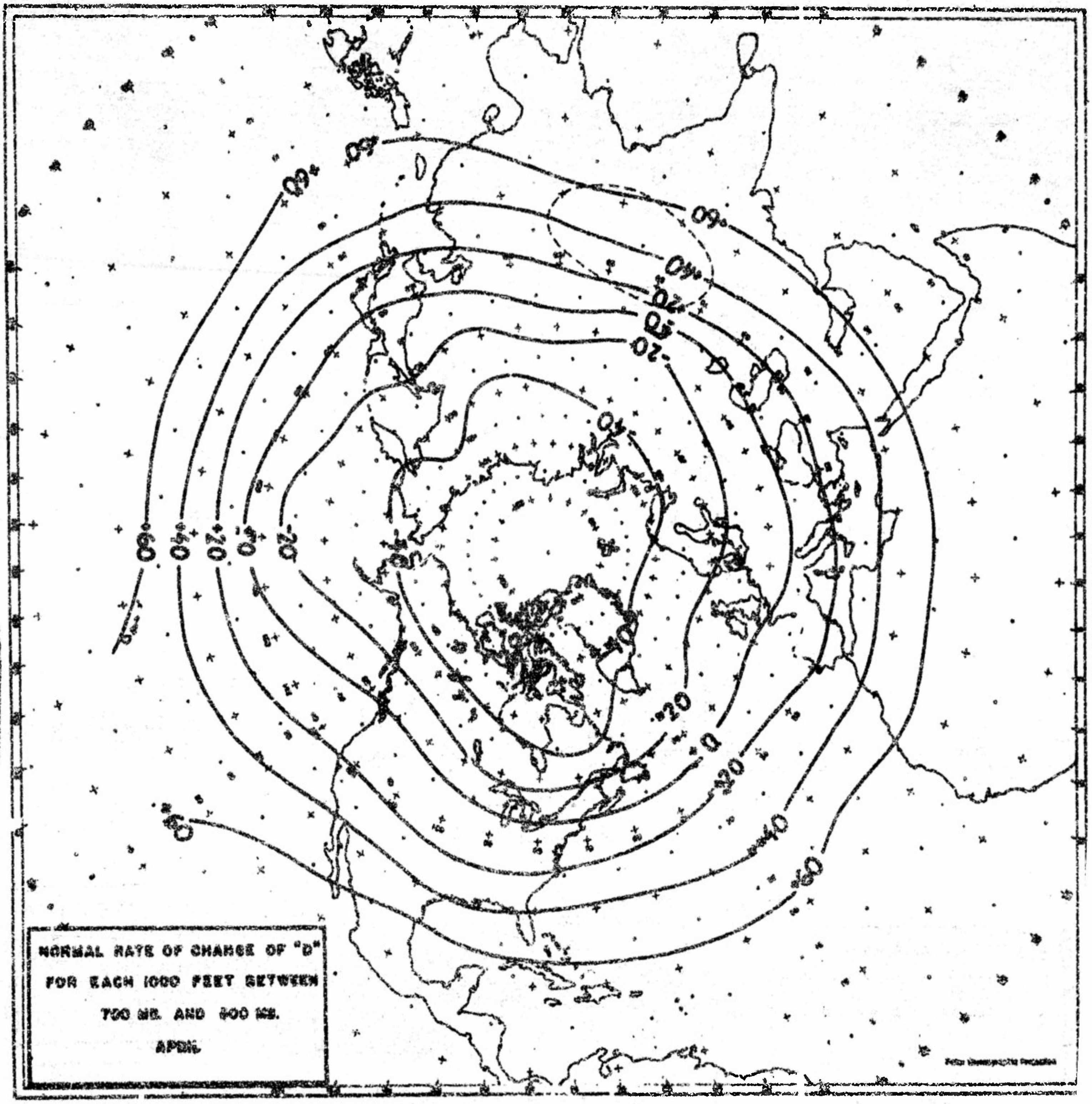


Figure (10). Upward Extrapolation Coefficient 700 mb to 500 mb, April

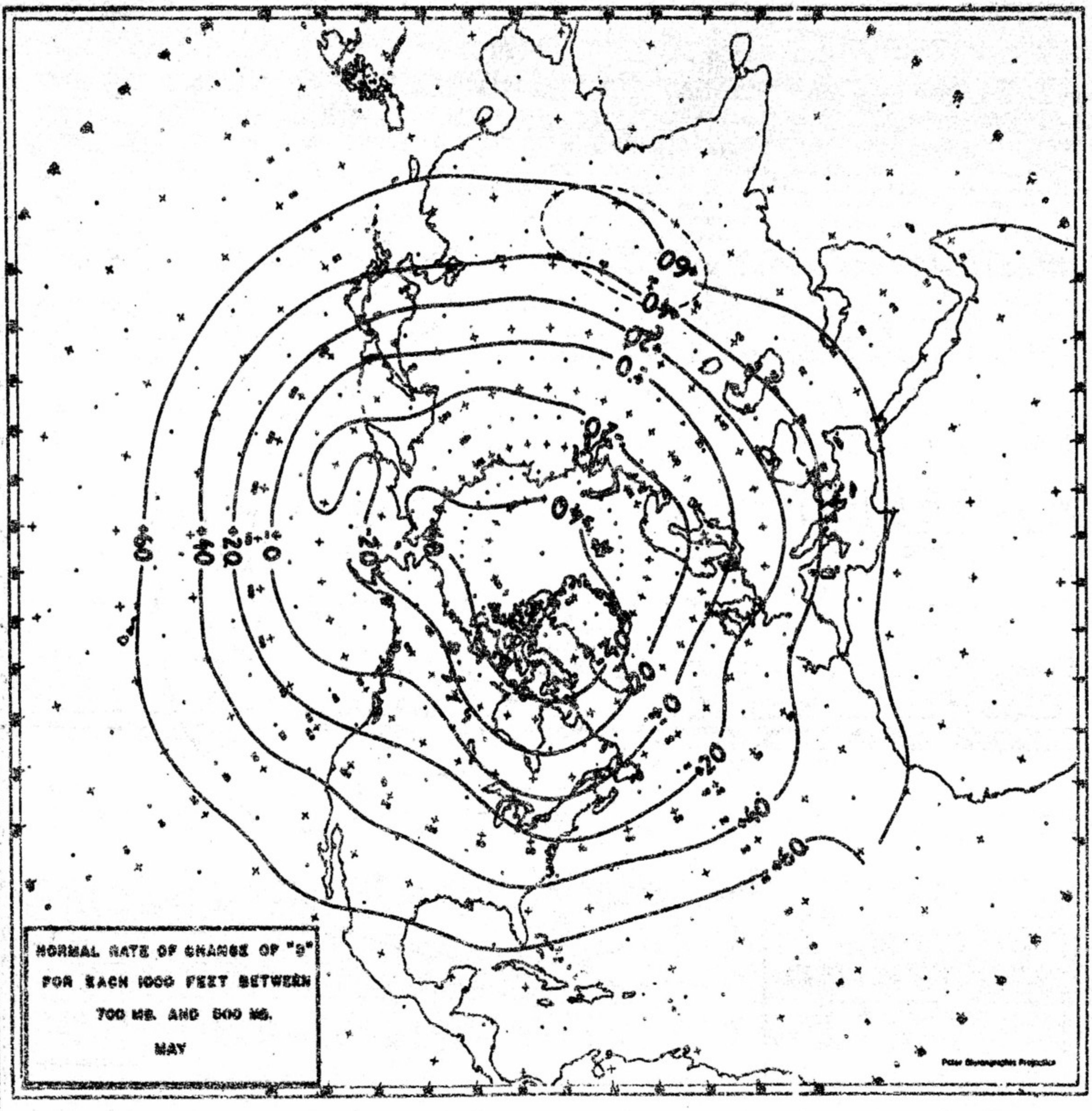


Figure (11). Upward Extrapolation Coefficient 700 mb to 500 mb, May

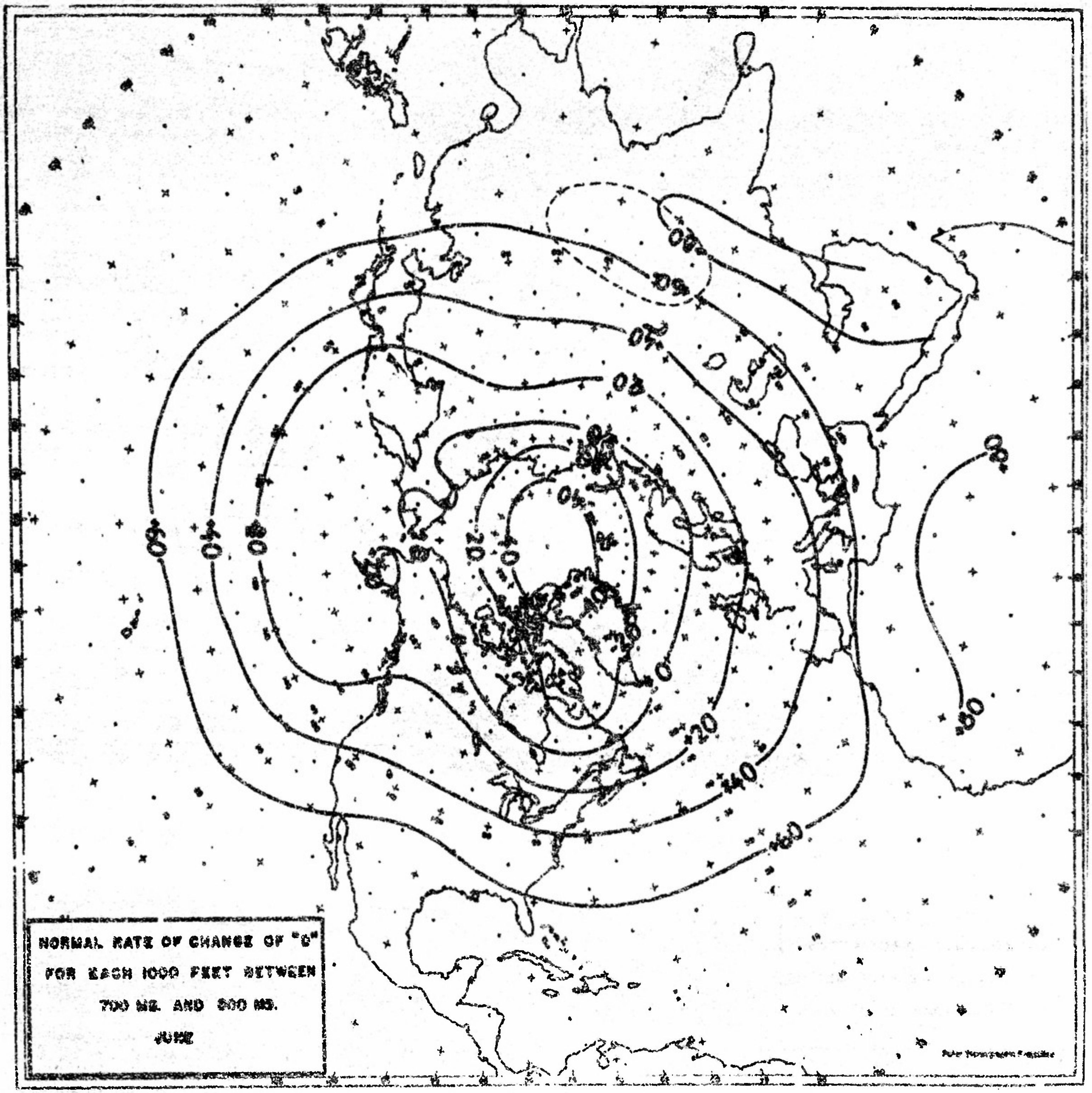


Figure (12). Upward Extrapolation Coefficient 700 mb to 500 mb, June

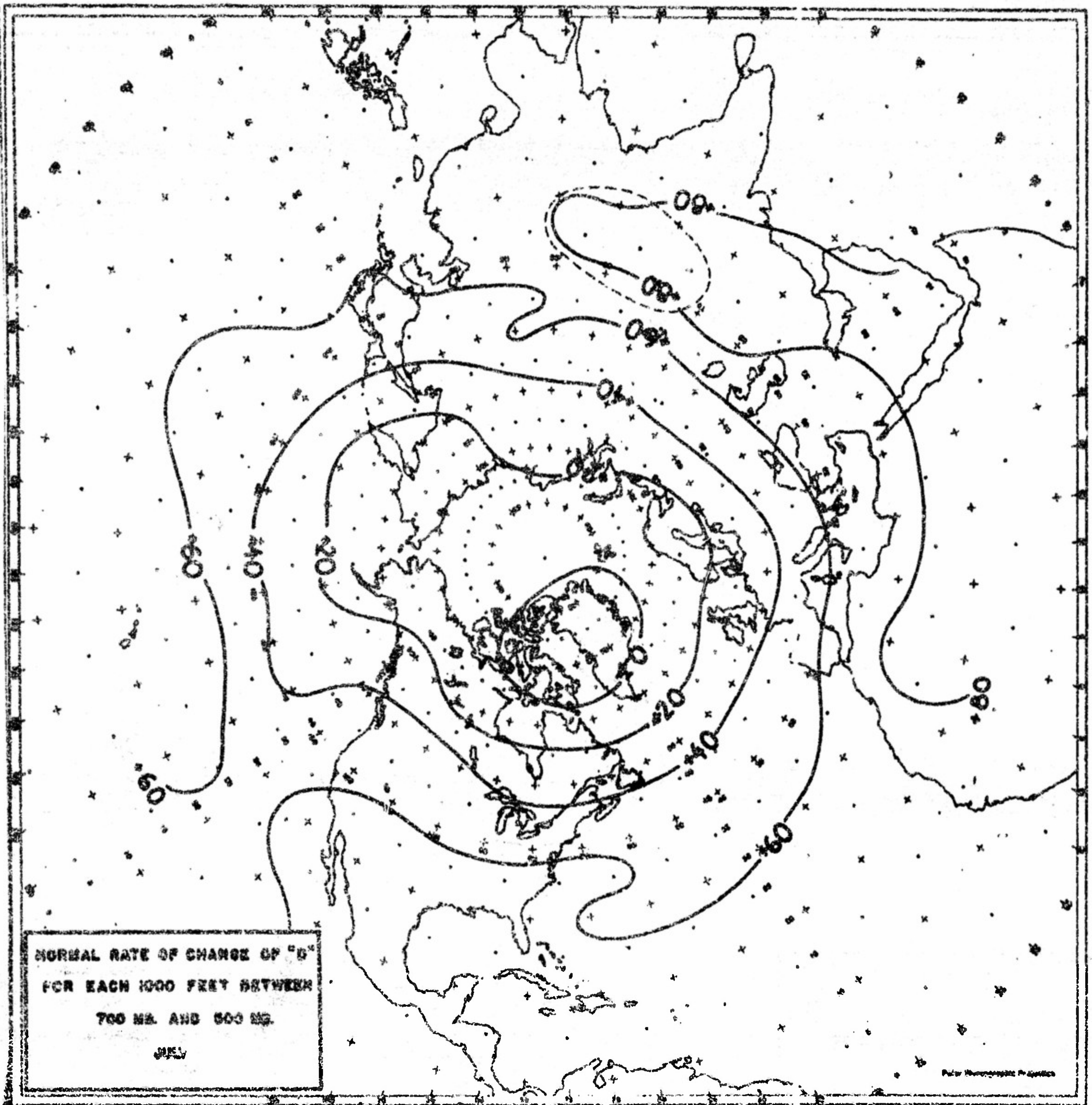


Figure (13). Upward Extrapolation Coefficient 700 mb to 500 mb, July

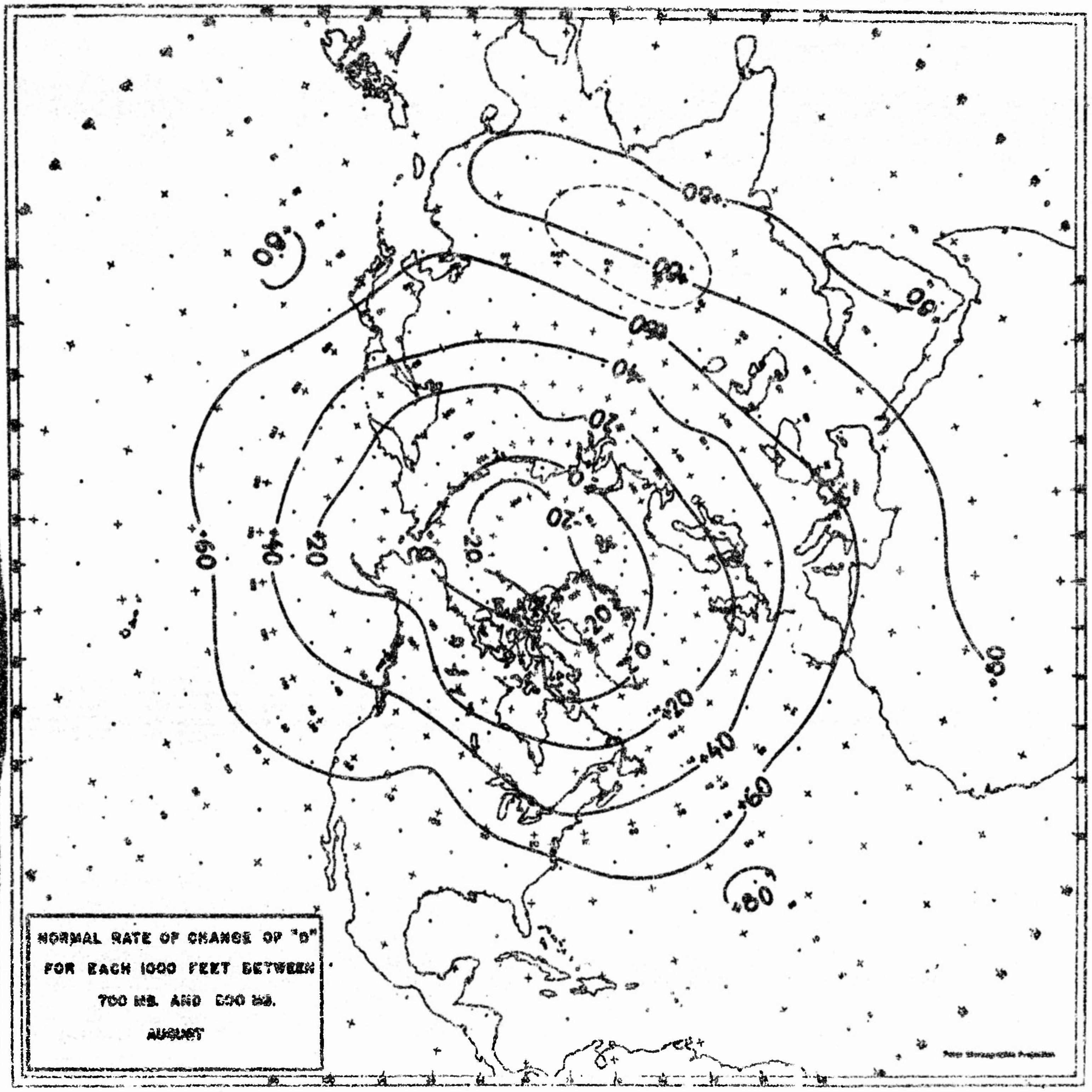


Figure (14). Upward Extrapolation Coefficient 700 mb to 5(. mb, August

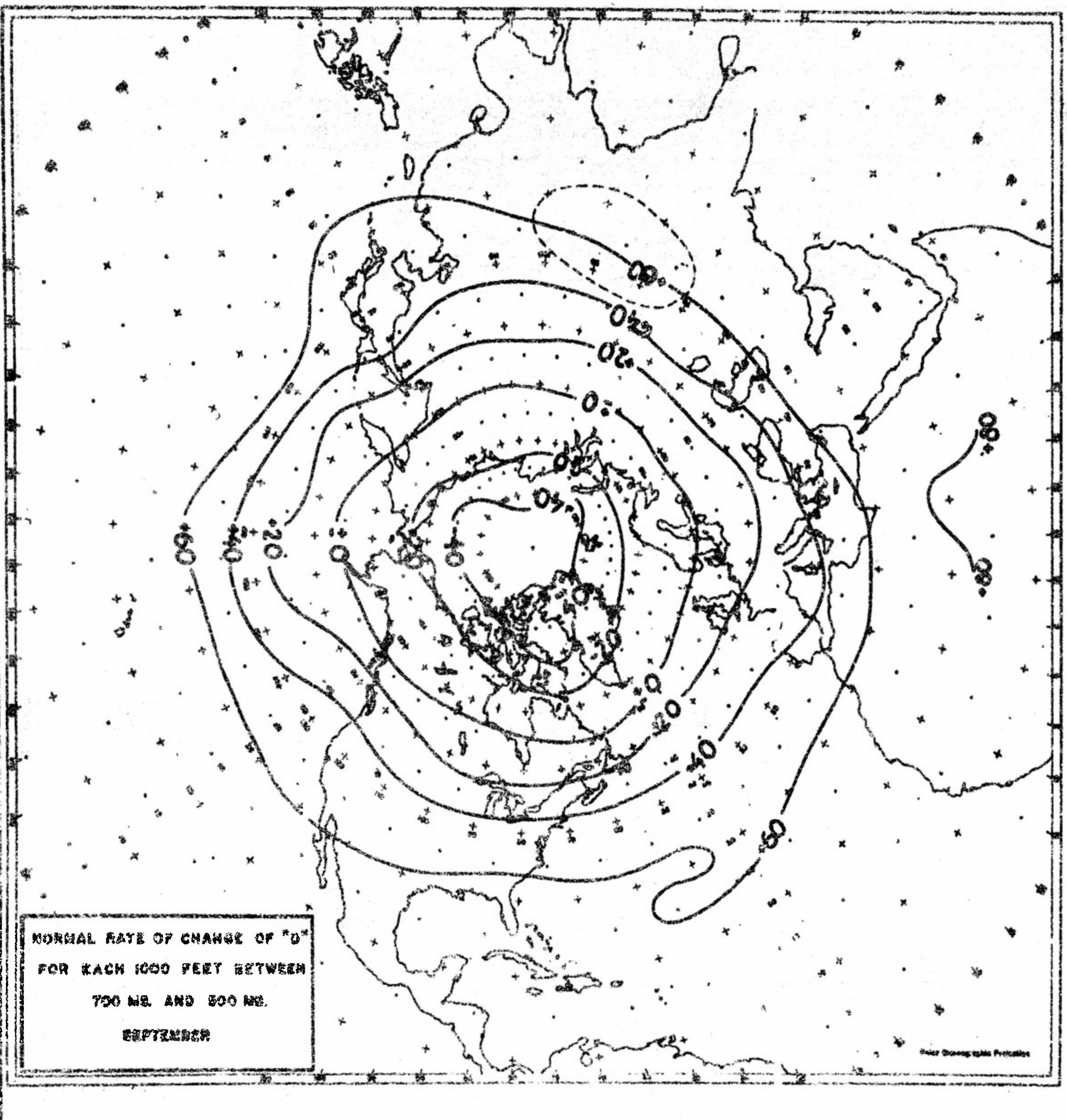


Figure (15). Upward Extrapolation Coefficient 700 mb to 500 mb, September

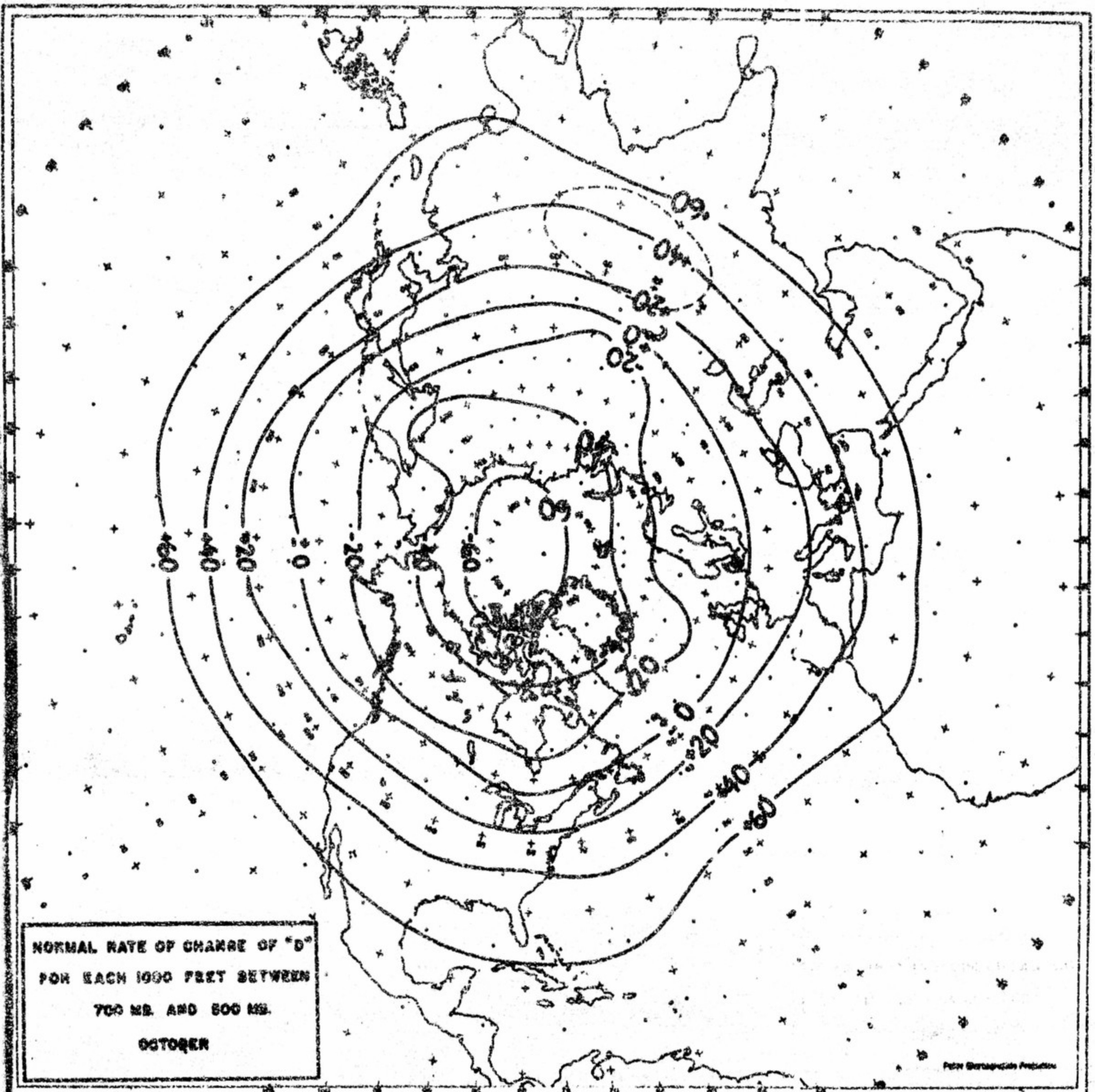


Figure (16). Upward Extrapolation Coefficient 700 mb to 500 mb, October

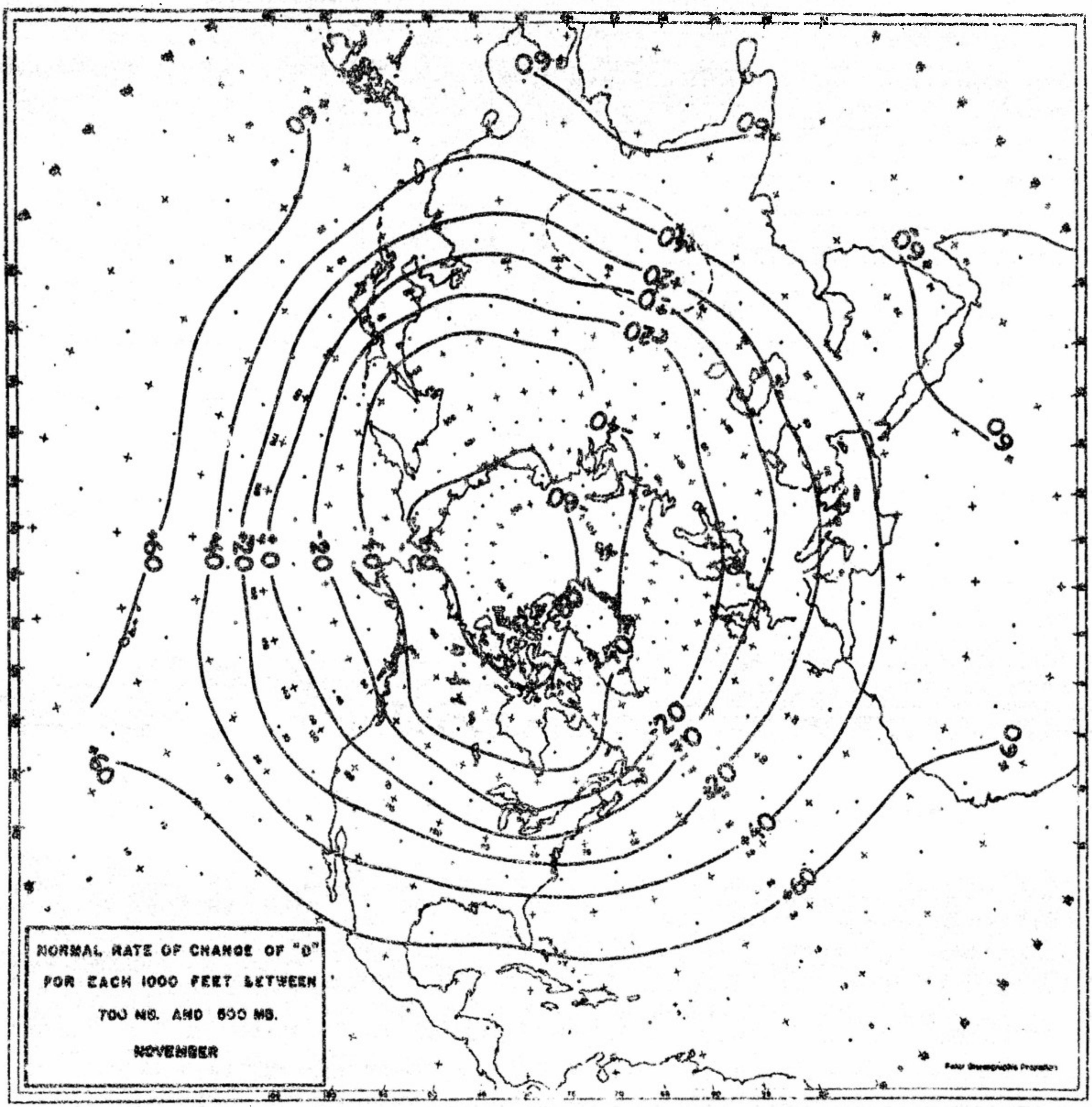


Figure (17). Upward Extrapolation Coefficient 700 mb to 500 mb, November

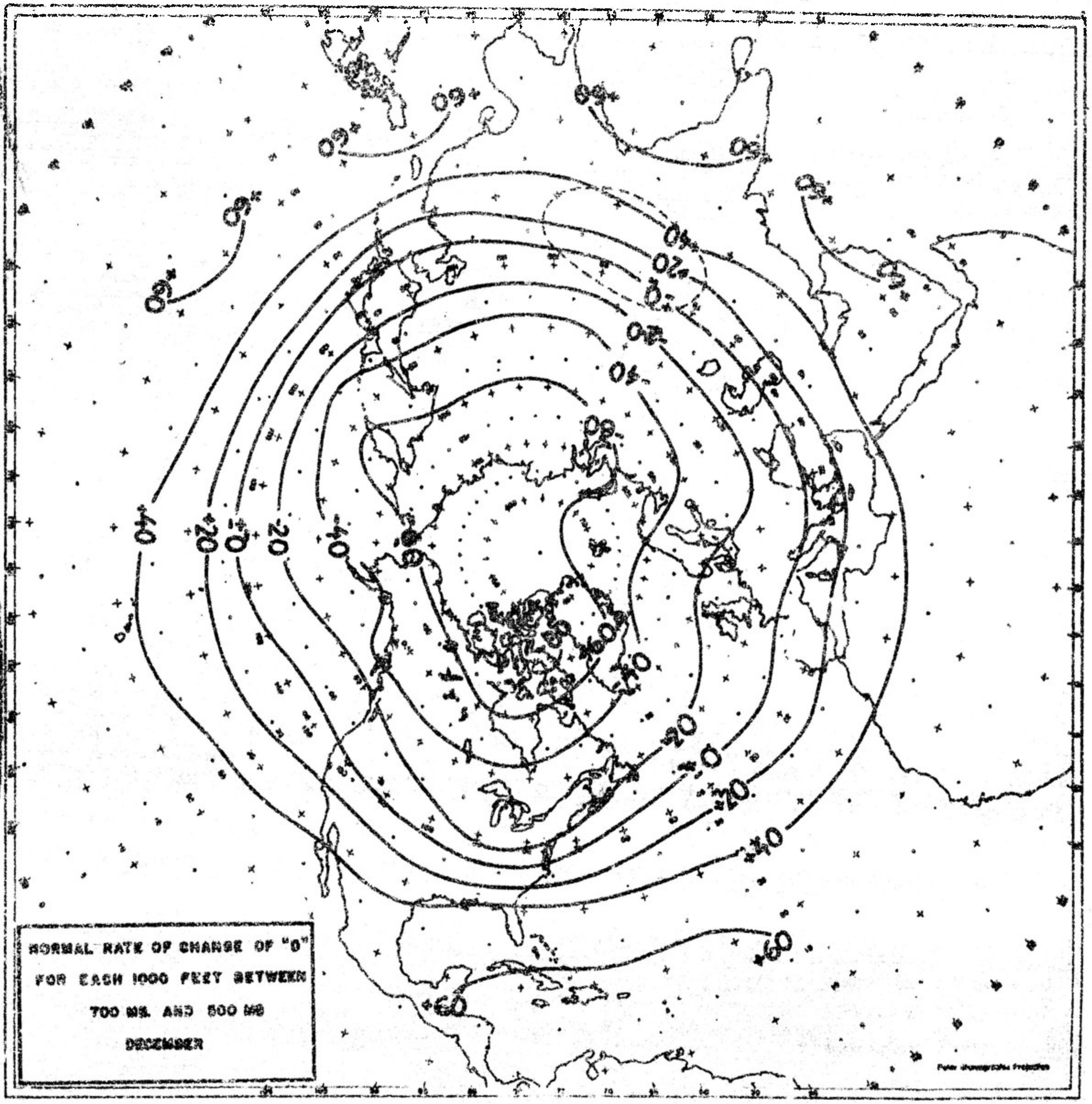


Figure (18). Upward Extrapolation Coefficient 700 mb to 500 mb, December

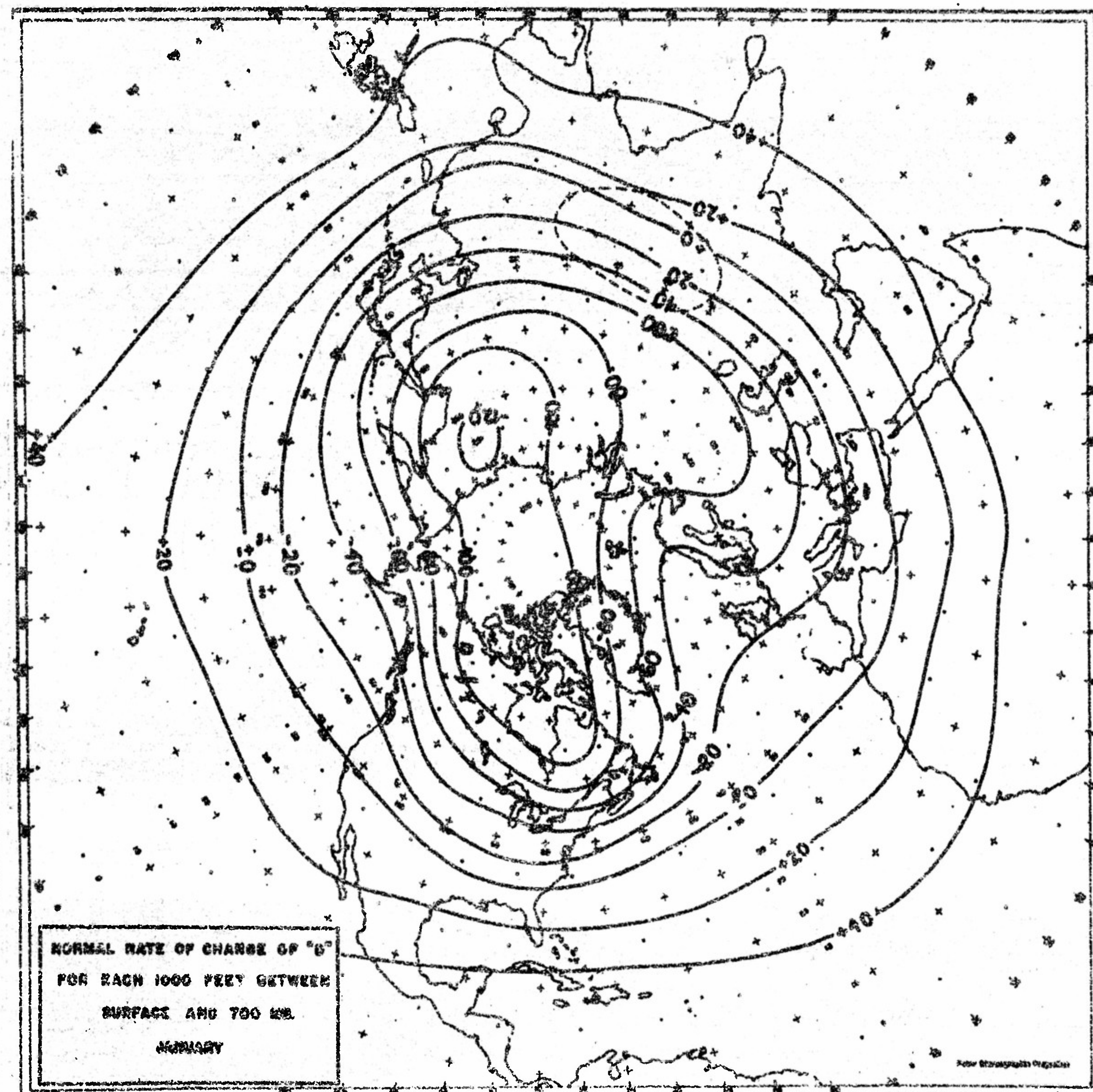


Figure (19). Upward Extrapolation Coefficient Surface to 700 mb, January

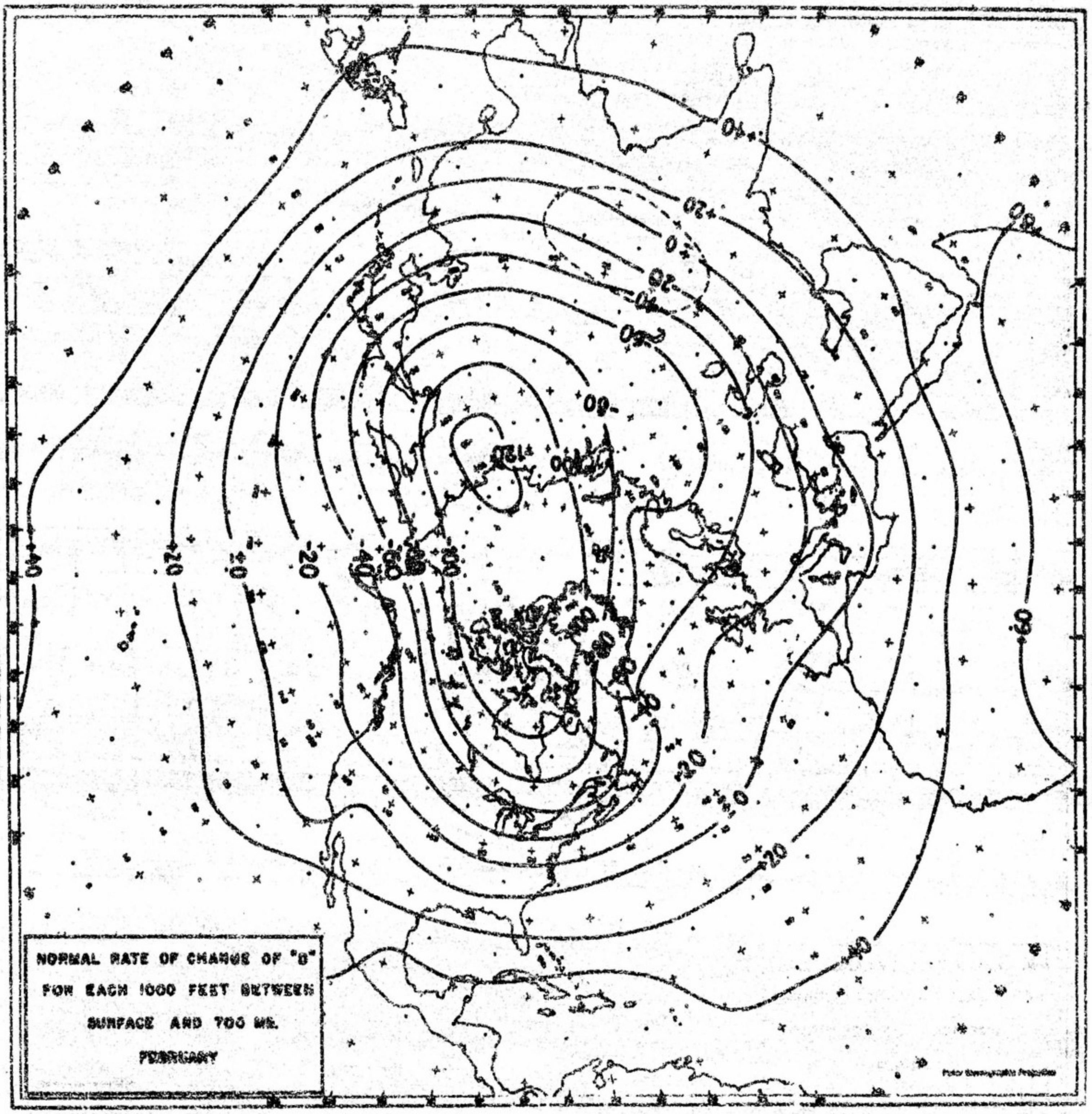


Figure (20). Upward Extrapolation Coefficient Surface to 700 mb, February

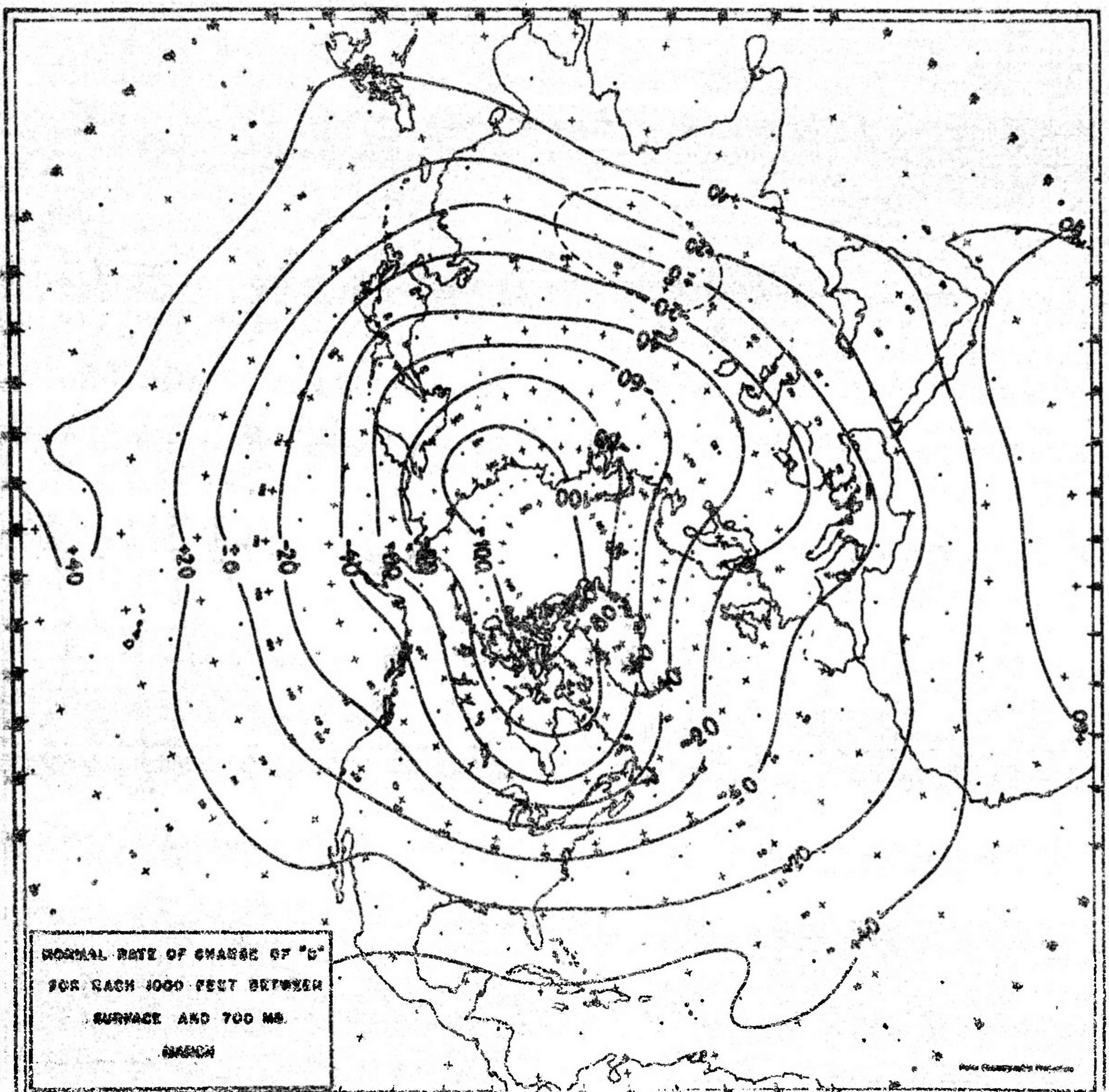


Figure (21). Upward Extrapolation Coefficient Surface to 700 mb, March

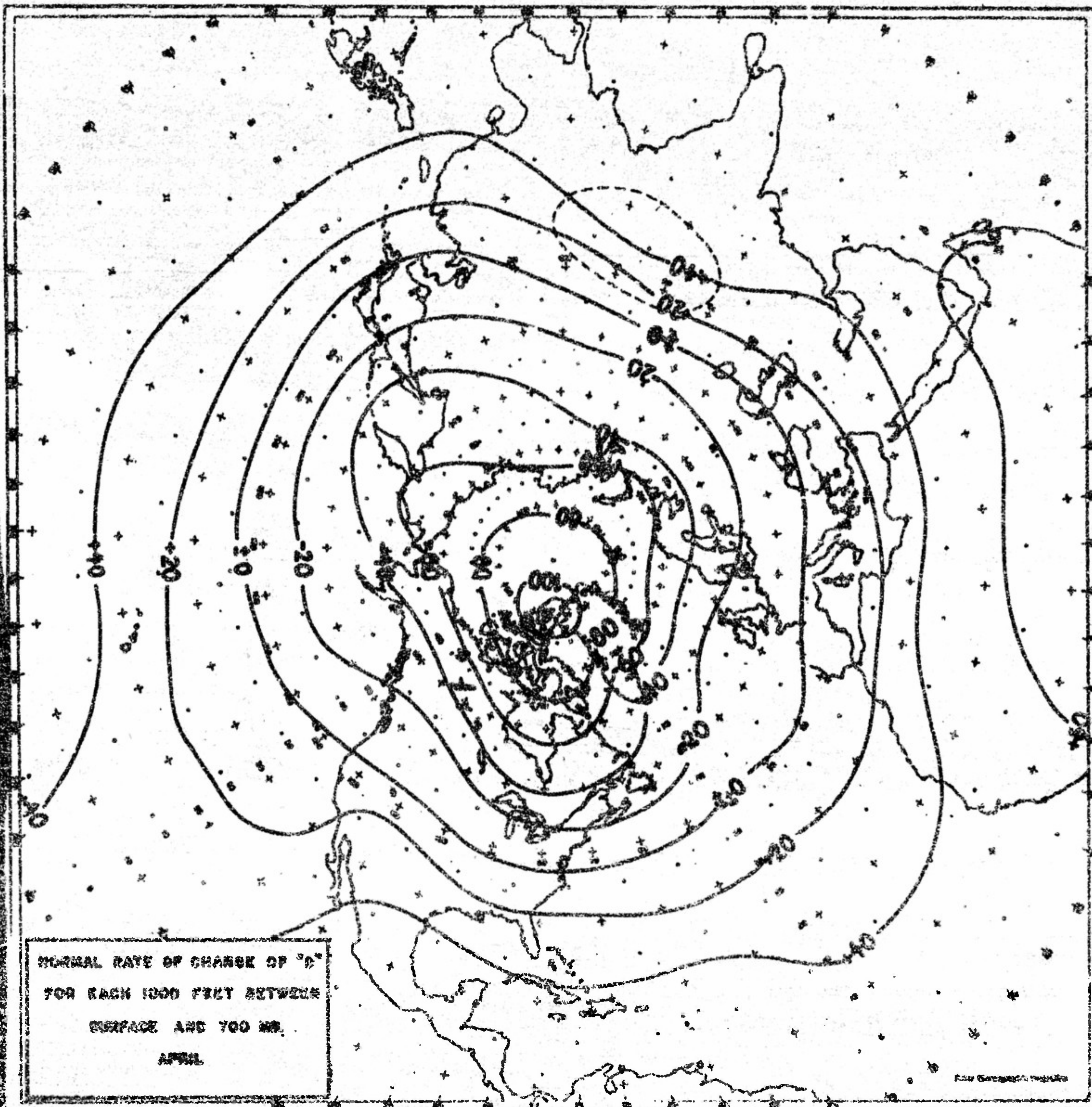


Figure (23). Upward Extrapolation Coefficient Surface to 700 mb, April

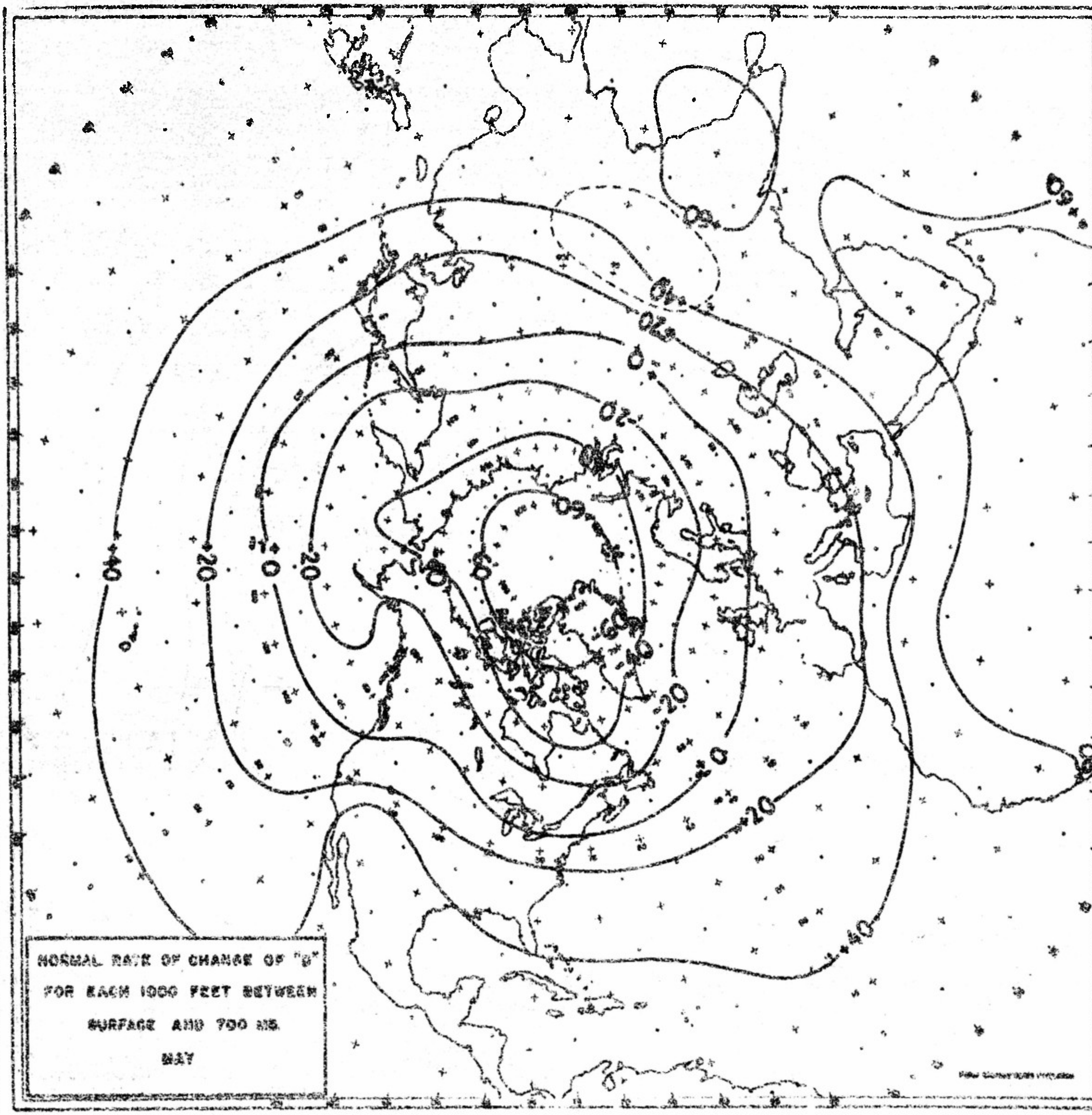


Figure (25). Upward Extrapolation Coefficient Surface to 700 mb, May

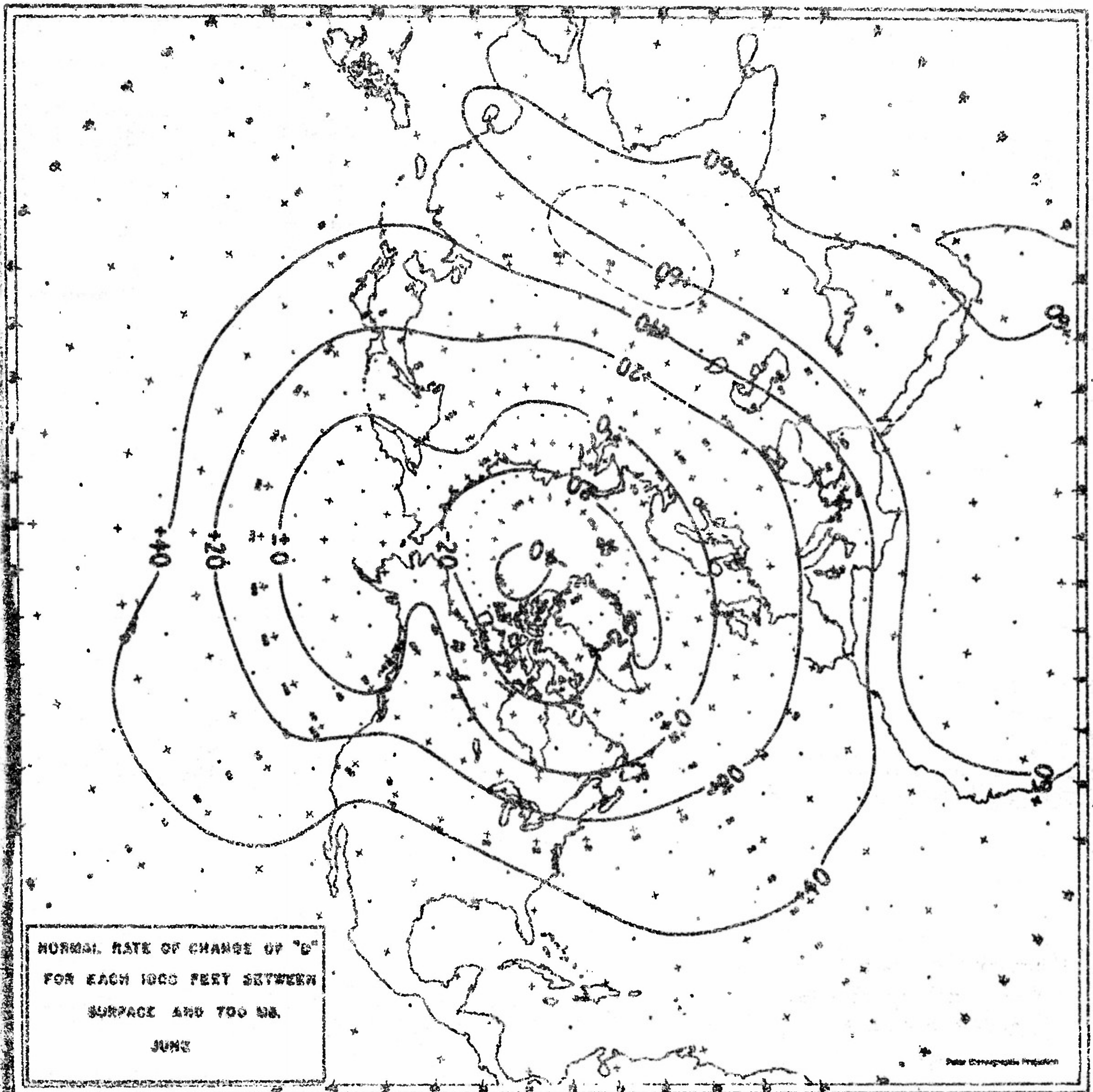


Figure (24). Upward Extrapolation Coefficient Surface to 700 mb, June

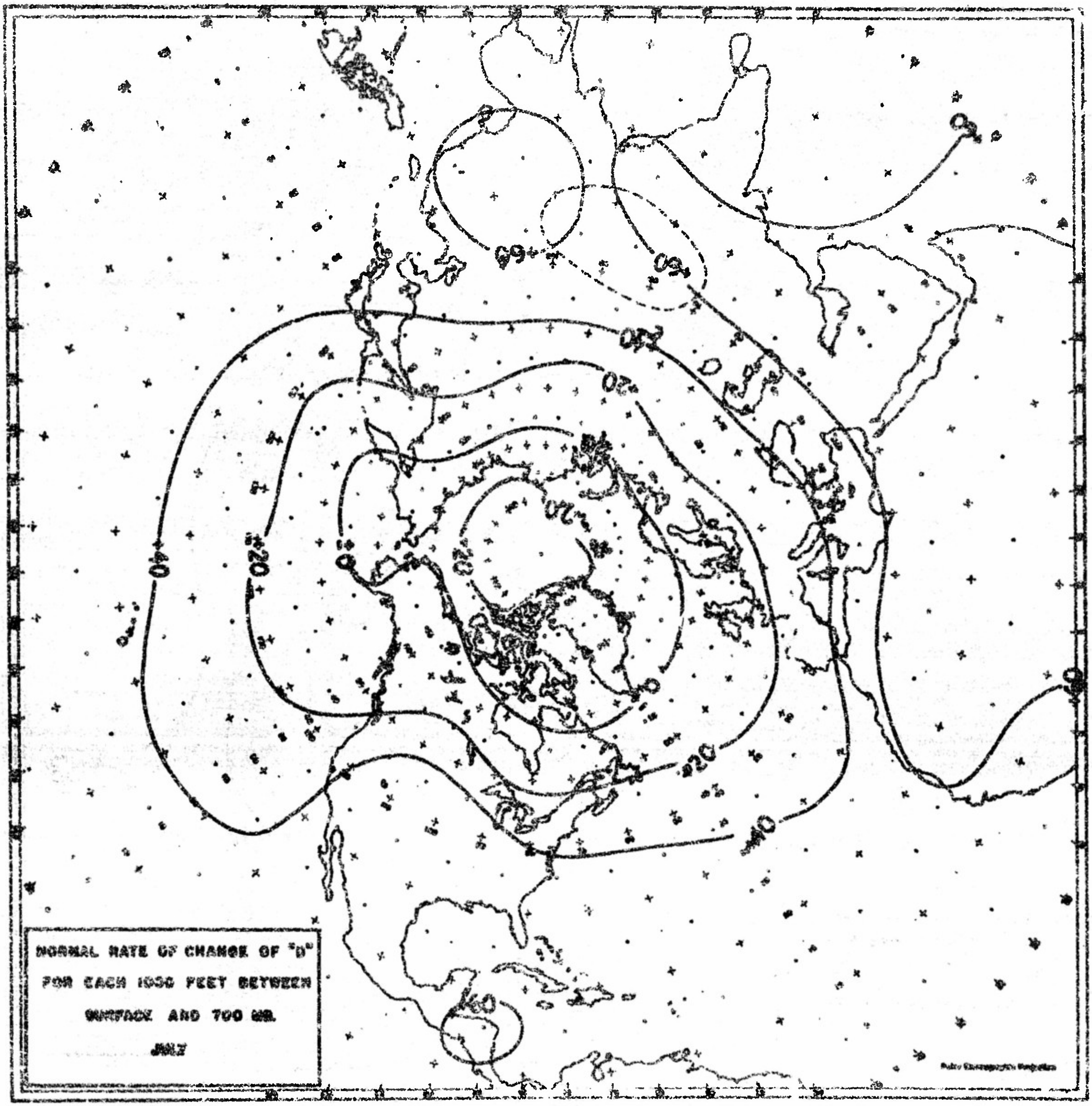


Figure (25). Upward Extrapolation Coefficient Surface to 700 mb, July

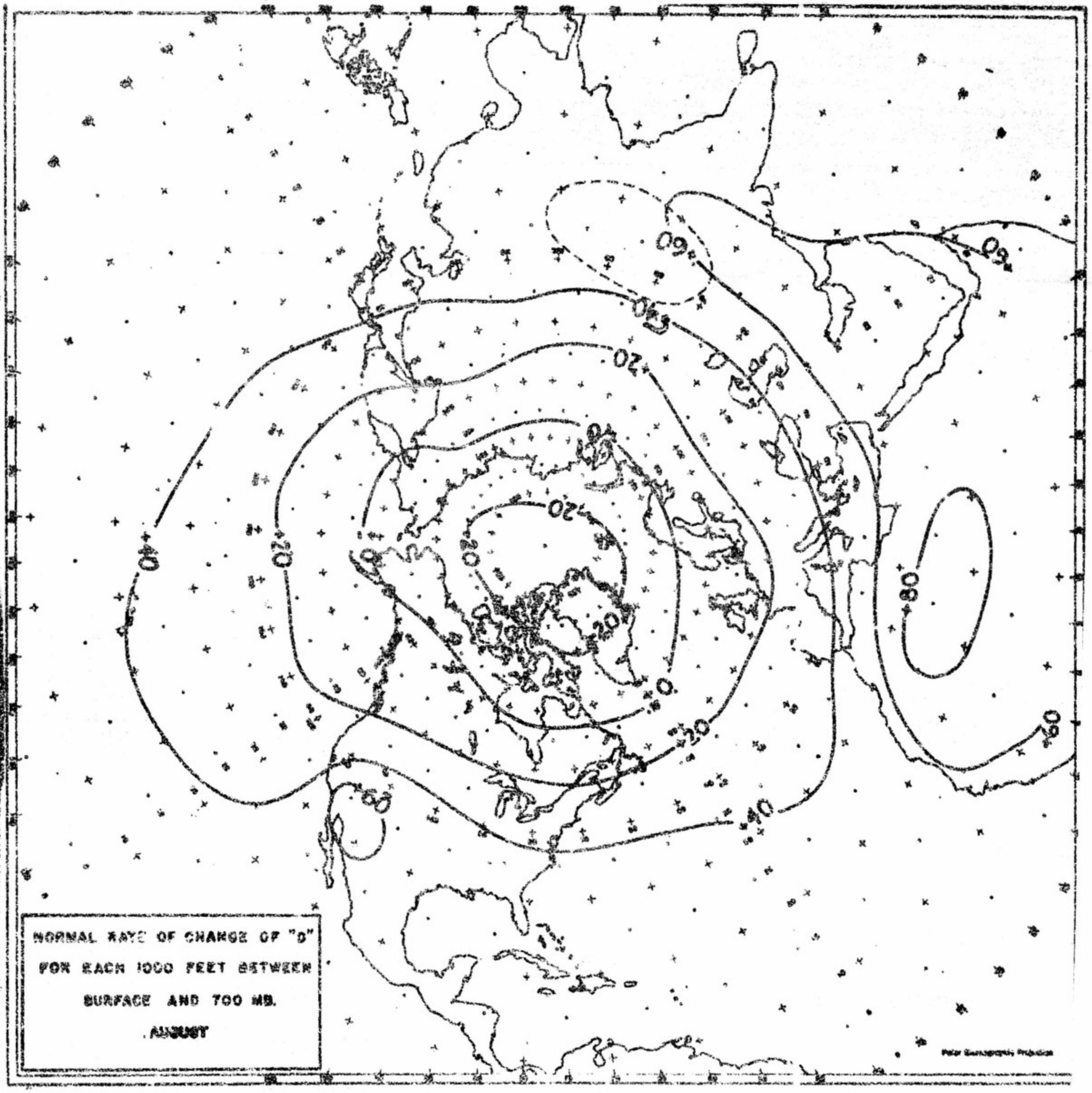


Figure (38). Upward Extrapolation Coefficient Surface to 700 mb, August

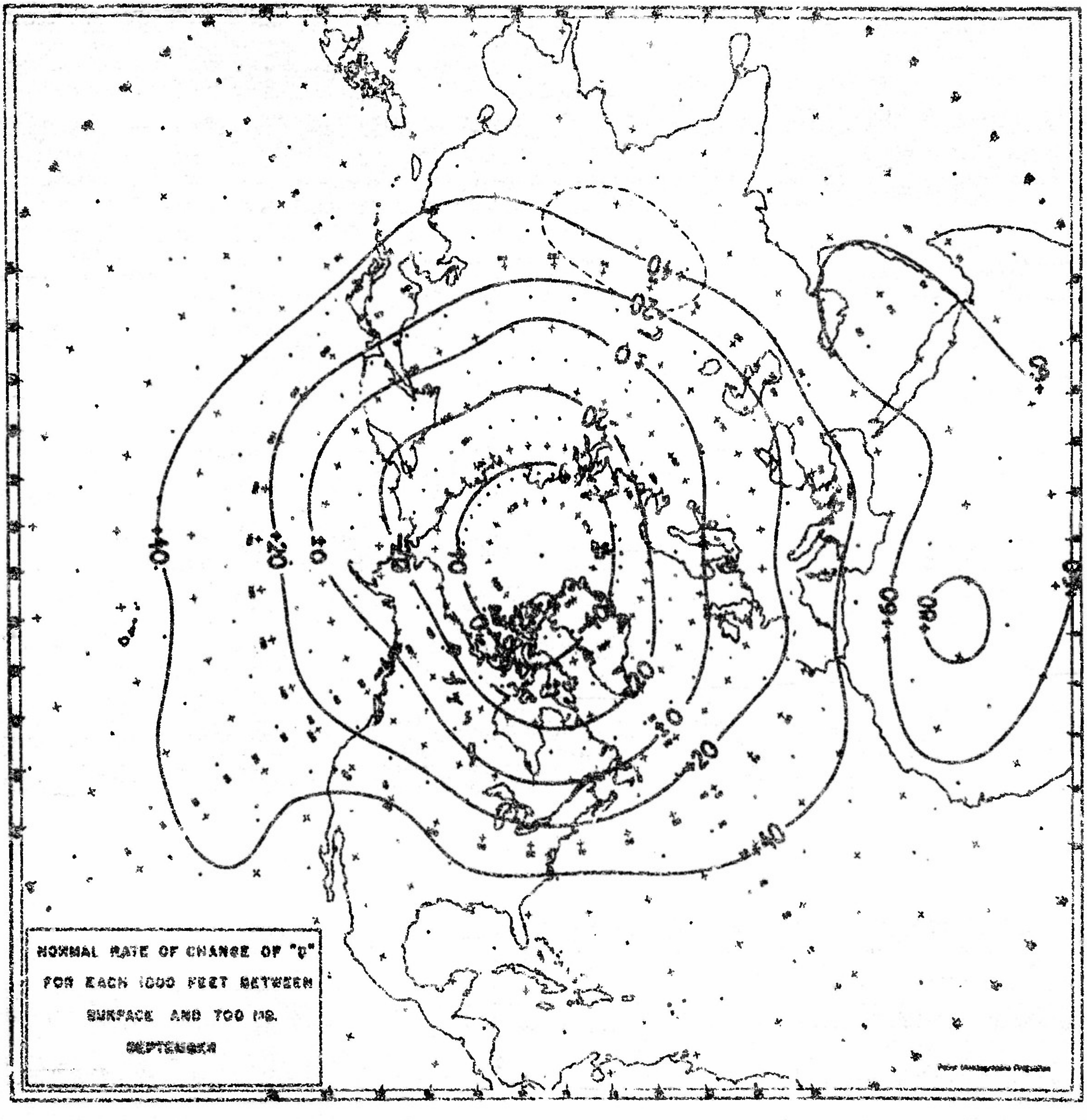


Figure (27). Upward Extrapolation Coefficient Surface to 700 mb, September

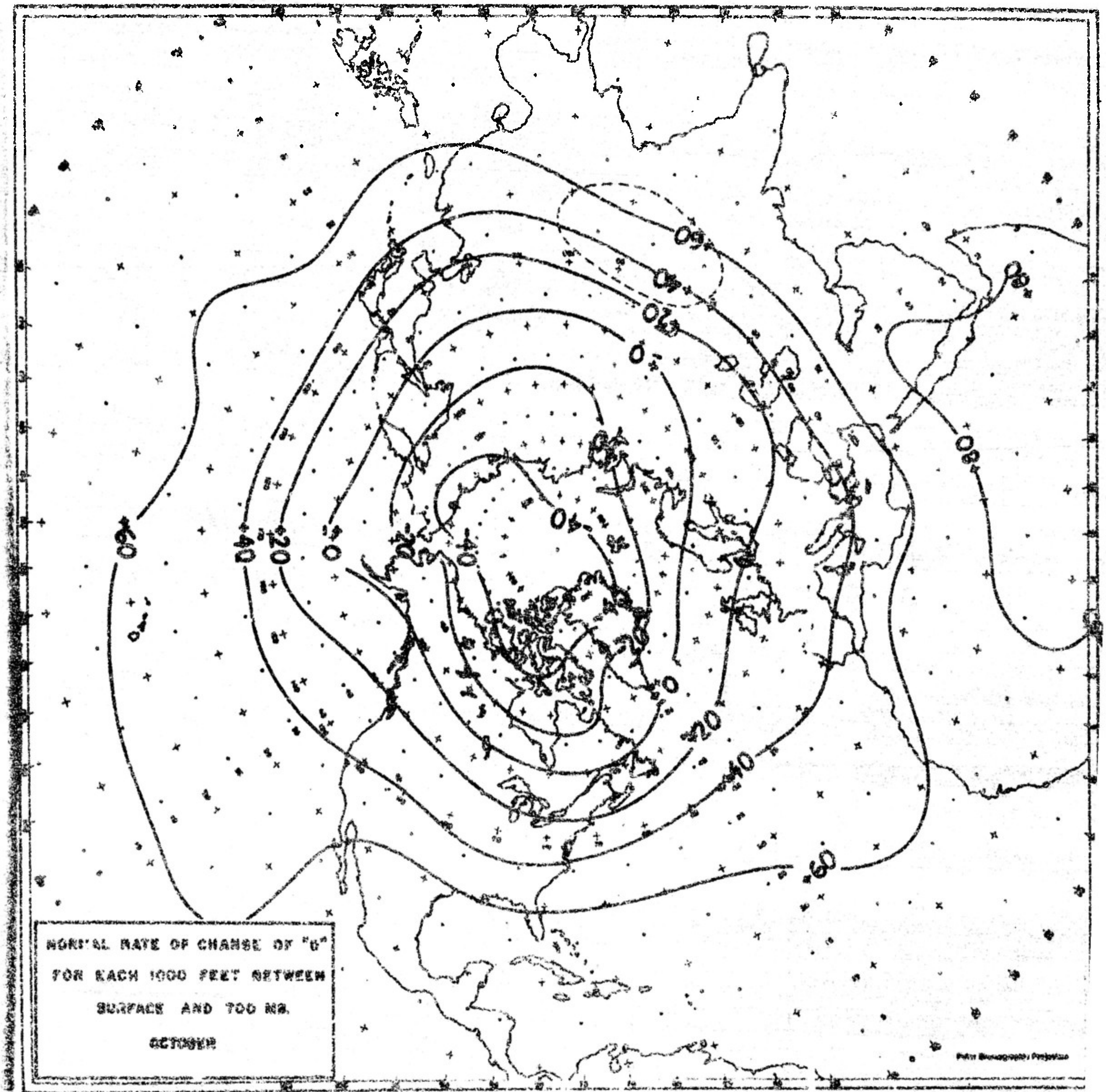


Figure (28). Upward Extrapolation Coefficient Surface to 700 mb, October

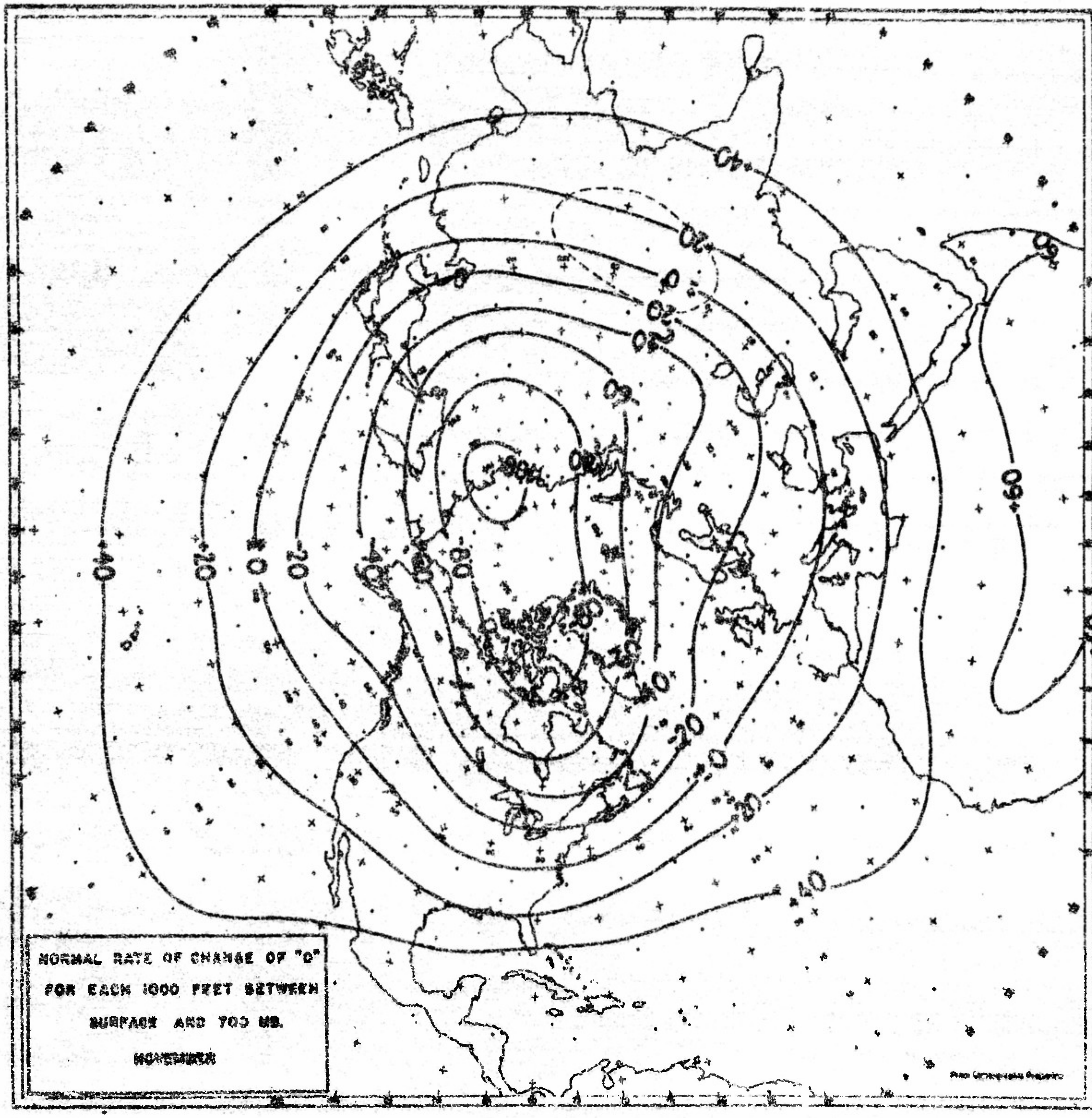


Figure (28). Upward Extrapolation Coefficient Surface to 700 mb, November

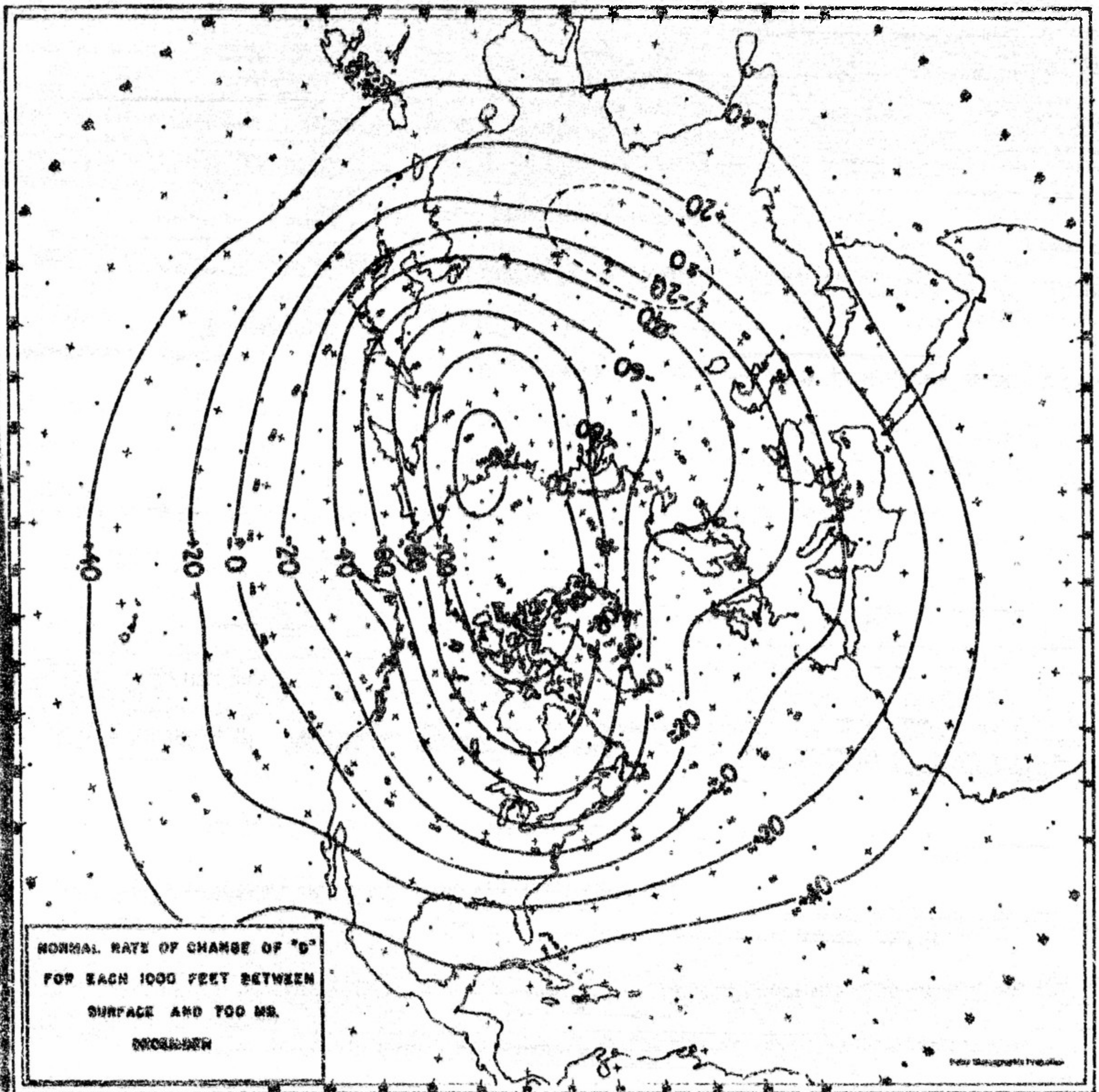


Figure (30). Upward Extrapolation Coefficient Surface to 700 mb, December

V. ERROR ANALYSES AND CLIMATIC STUDIES

In any meteorological forecasting problem the meteorologist is materially aided if he has available a knowledge of the errors resulting from various prediction schemes. A sound knowledge of the frequency distributions of the parameters he is to forecast is often fundamental. This is usually obtained from climatic studies of various types.

A. Error Analyses

Subsequent to the analysis of WBAN analysis center prognostic errors reported fully in the Final Report on Phase I of the Pressure-Height Prediction Project by AROWA, the Meteorological Division of the Aerophysics Research Foundation, under contract to Project AROWA, conducted a further investigation of errors attained in various prediction procedures. Comparisons were made of the forecast accuracies of: a skilled forecaster, zonal theoretical forecasts and linear zonal extrapolations. It was determined that forecasts prepared by a skilled forecaster experienced in long-range hemispheric forecasting will predict the height of a constant pressure surface with greater accuracy than will a forecast prepared by use of a persistence technique or of the one dimensional numerical forecast scheme. Additionally, tests indicated that an experienced forecaster was considerably more accurate than estimates derived from linear zonal extrapolation of isallophyptic centers.

These investigations substantiated the conclusions reached independently at AROWA that the techniques employed by forecasters experienced with long-range forecasting techniques provided the most successful forecasts yet developed. Concentration of attention on these techniques and their formalization into a useable prediction scheme was indicated.

B. Climatic Studies

As indicated by the schematic diagram of Figure 1 in Chapter I, a knowledge of the climatology of the parameters to be predicted is basic to any successful prediction procedure. The required climatic information may assume many forms other than the commonly encountered sets of statistics found in climatological summaries.

In these investigations the 500-mb surface has been considered as a level of primary interest because of its physical characteristics relating to the pressure-height parameters required. A climatology of the 500-mb surface had never been prepared, largely because sufficient data had never before been assembled in useable form. With the aid of the machine tabulation equipment at the National Weather Records Center at Asheville, N. C., a climatology of the 500-mb surface was developed. This assumed the form of numerous tabulations and frequency distributions of height and 24-hour height change data; statistical tables and graphs pertaining to the frequency, intensity and duration of recognizable synoptic patterns such as blocking, long waves, etc; spatial distribution charts for several forms of frequency tabulations of height data; sectional and hemispheric spatial diagrams and tables of zonal wind speed data and tables of classes and limits derived from these. Simultaneous studies of the synoptic climatology of recognizable patterns were undertaken at AROWA and at the Aerophysics Research Foundation.

These climatic investigations provided much of the basis for the material contained in Volume II of this report.

Climatic information on the distribution of 500-mb heights and 24-hour changes for each grid point on a 5° latitude-longitude diamond grid for each half of all calendar months, as described in Progress Report No. I - Phase II of this project, was summarized in tabular form. An example of the tabulations for the first half of January, for the period of available records, at 45° N, 160° W is shown in (31). A total of 5,840 such tables were prepared. The material they contain was utilized in several studies relating to this task. Charts were constructed of the space distribution of the total range of heights for each half month (averaged over 7 years), the space distribution of the range

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MO	S	I	O	LAT	HT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOT	A	B	C
01	1	B	2	45	91							3	1								4			
					89						1	3	3	2							9			
	E = 24				87						2	1		4	1						8			
	F = 12				85				1		1	3	2	5	1						13			
					83					2	1	2	4	3							12			
					81					2	2		2	3	2						11			
					79					1	1	1		2	2	1	1				9			
					77			1			1	7	4	2		1					16			
					75						2		2	5	2						11			
					73							2		1	3	1					7			
					71									1	1	1	1				4			
					67														1		1			
					-			1	1	5	11	22	18	28	12	4	3		1		105	84554	2914	98

D = 805.3

Legend:

MO	is month (January	
S	is half of month (First)	
I	is longitude indication	} (Longitude 160° W)
O	is octant	
LAT	is latitude (45° N)	
HT	is class limit designator for 500-mb height (91 = 19,000 to 19,199 ft.)	
	Numbers across top are class designators for 24 hr., 500-mb ht. change (8 = -99 to +99 ft., 1 = -1499 to -1300 ft., etc. to 15 = +1300 to + 1499 ft.)	
TOT	is the number of cases falling in each height class.	
	Numbers in bottom row of table are the cases falling in each height change class.	
A	is sum of heights	
B	is absolute sum of height changes	
C	is algebraic sum of height changes	
D	is average height	
E	is range in hundreds of feet of 99% of height observations	
F	is range in hundreds of feet of 68% of height observations	

Figure 31. Tabulation of Heights vs Height Change at 500 mb.

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of height values including 68% of all observations, the geographic distribution of frequency diagrams of height and 24-hour height change and the distribution of specific characteristics of these frequency distributions. These are not all reproduced in this report, as the information they contain has not been fully processed and the inclusion of such a bulk of tabular material is unwarranted.

For the studies of large scale circulation features, a set of 500-mb charts smoothed by means of time averaging over 5-day periods was constructed. This was accomplished by having the punched card machines add the heights at each grid point for five successive days, then drop the first and add a sixth day, etc. The tabulations of the height sums were plotted and analysed at AROWA, resulting in a seven year sample of consecutive 5-day mean 500-mb charts. A sample of such a chart is shown in Figure (32).

For the study of 500-mb height patterns related to extreme anomalies at selected geographic points, height sums at all grid points were listed for the 20 dates having the highest recorded heights and the 20 dates having the lowest recorded heights at each of 16 selected grid points over the Eurasian continent. This was accomplished by the tabulating machines. The values were then plotted on charts and analysed. The resultant patterns are discussed in Volume III.

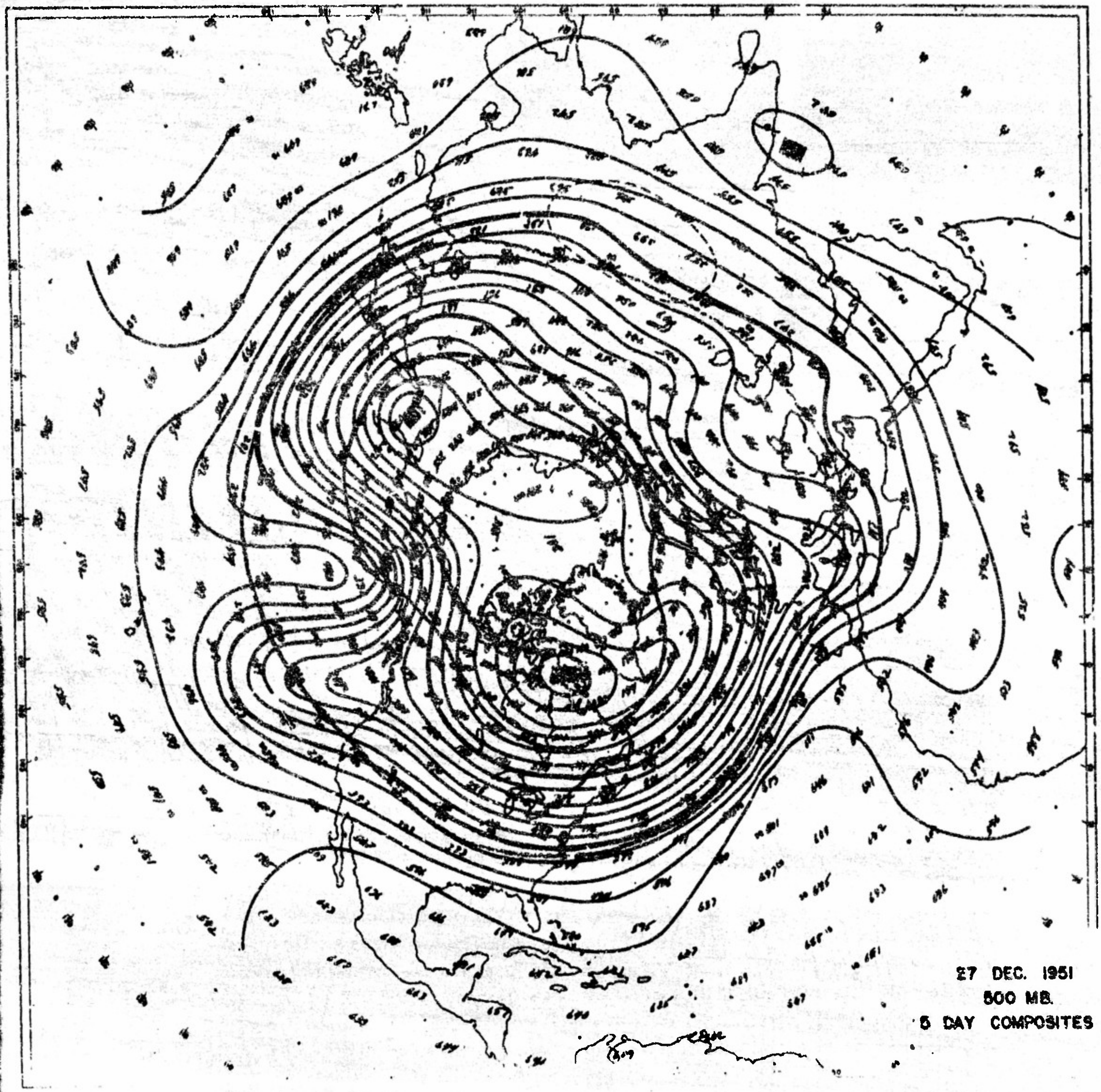

Figure (32). Five-Day Mean 500-mb Chart for 25-29 December 1951

To obtain information on the relation of the zonal west wind component to large scale circulation anomalies, the heights at the grid points on each latitude belt were summed by octants and the hemisphere. The differences between the sums for adjacent latitude bands in each octant and the hemisphere were obtained by the tabulating machines. From these the zonal wind values were computed in meters per second for each latitude band in each octant and the hemisphere for individual days, three-day rolling means, and consecutive half monthly periods. These are discussed in detail in Volume II, Chapter V.

Early attention was devoted to a study of the synoptic climatology of blocking patterns. These were discussed in the first two progress reports of Phase II of this task. A further discussion is contained in Volume II, Chapter IV of this report.

The Aerophysics Research Foundation, as a part of their contract work on this project developed a climatology of trapped lows, which is contained in their report to Project AROWA. Though it is not reproduced in full here, the results of the study have been incorporated in the blocking section of Volume II, Chapter IV of this report.